PROJECT FINAL REPORT

Final publishable summary report

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Executive summary

SYNER-G is a European collaborative research project focusing on s**ystemic seismic vulnerability and risk analysis** of buildings, transportation and utility networks and critical facilities. The methodology is implemented in an open source **software tool** and it is applied and validated in selected **case studies**. SYNER-G is integrated across different disciplines with an internationally recognized partnership from Europe, USA and Japan. The 14 participants in the consortium represent a variety of organizations, from universities and academic institutions to research foundations and SMEs. The objectives and the deliverables are focused to the needs of the administration, local authorities, responsible for the management of seismic risk, private and public services managing utility systems and infrastructures, insurance industry, as well as the needs of the construction, consulting and insurance industry.

SYNER-G developed an innovative methodological framework for the assessment of physical as well as socio-economic seismic vulnerability at urban and regional level. The built environment is modeled according to a detailed **taxonomy** into its component systems, grouped into the following categories: buildings, transportation and utility networks, and critical facilities. Each category may have several types of components. The framework encompasses in an integrated fashion all aspects in the chain, from regional **hazard** to **fragility** assessment of components to the **socioeconomic impacts** of an earthquake, accounting for relevant **uncertainties** within an efficient quantitative simulation scheme, and **modeling interactions** between the multiple component systems in the taxonomy. The **prototype software** (OOFIMS) is implemented in the **SYNER-G platform,** which provides several pre and post-processing tools. The methodology and software tools are applied and **validated** in selected sites and systems in urban and regional scale: the city of Thessaloniki (Greece), the city of Vienna (Austria), the harbour of Thessaloniki, the gas system of L'Aquila (Italy), the electric power network in Sicily, a roadway network in South Italy and a hospital facility again in Italy. Adequate **guidelines** and appropriate **dissemination** schemes for all products of the project at European and international level have been proposed, including among others seven European Reference Reports, synthetic documents and deliverables, high quality brochure and leaflet, three technical workshops, a special session in the 15WCEE, peer review publications in journal and conferences, and preparation of two books in Springer Editions.

The main features of the SYNER-G methodology are outlined in the following:

- Unified and harmonized **typology and taxonomy** definitions are proposed for almost all physical assets at risk in the European context.The physical elements are the built environment namely buildings, lifeline networks, transportation infrastructures, utilities and critical facilities. Social elements are fatalities, incuries and various social and economic losses, which are evacuate based on the availiable demographic and socio-economic data. It is essential to compile **inventory** databases of elements at risk and to make a classification on the basis of pre-defined typology definitions. Inventories are obtained from Census Data, Owner/Operators Data, and ground surveys or through remote sensing techniques.
- **Fragility curves** are proposed for all elements at risk based on SYNER-G taxonomy, using available data and developing new ones if needed. A **Fragility Function Manager Tool** is available for the storage, harmonization, utilization and comparison of all available fragility functions.
- The **seismic hazard** is defined based on SHARE EC/FP7. A stochastic simulation is performed for the generation of spatially correlated and cross-correlated fields for ground motion intensity measures (called "Shake-fields"). Site effects and various geotechnical hazards (liquefaction, fault crossing, landslide displacements) are also considered.
- A **systemic analysis** methodology and tool is developed for buildings, utilities and lifelines (electrical power, water, waste water, gas, transportation and harbor networks and health care facilities). The **Object-Oriented Modeling paradigm** is used (called here after OOFIMS), where the complex problem of several interacting systems is decomposed in a number of interacting objects. Each system is specified with its components, solving algorithms – interactions between components, performance indicators (PIs) and interactions with other systems.
- An advanced innovative systemic vulnerability assessment is carried out considering uncertainties based on Monte Carlo or importance samping simulation. **Damages and losses** for all assets are assessed. Representative results are building damages, casualties (deaths, injuries, displaced people), connectivity or flow analysis-based performance indicators for networks and infrastructures and mean annual frequency of exceedance of the PIs. Distribution of estimated damages and losses for specific events is given through thematic maps.
- Socio-economic losses are assessed including s**helter needs, health impact and accessibility models**. A Multi-criteria Decision Analysis tool is applied, which provides decision makers with a **dynamic decision-support platform** to capture post-disaster emergency shelter demand decisions. Apart from building and utility losses, building usability, building habitability and social vulnerability of the affected population together with socio-economic indicators (Urban Audit/EUROSTAT) are considered in the analysis.

Summary description of project context and objectives

Main objectives:

- **Encompass all past and ongoing knowledge and know-how on this topic to develop new innovative and powerful tools for seismic risk assessment.**
  Review of current state of the art, understanding of systemic vulnerability and risk of assets and urban systems (buildings, building aggregates, lifeline networks, utilities and infrastructures); development of a general methodology to assess vulnerability and losses including the inter and intra dependencies.

- **Select and develop advanced fragility functions and methods to assess the physical and societal-economic vulnerability of all assets.**
  Appropriate fragility curves/functions are proposed for numerous elements at risk (buildings, building aggregates, utility and transportation components and critical facilities) according to the typological features of European construction and practice.

- **Propose the most appropriate means of selecting seismic scenarios at system level.**
  Development of an enhanced seismic hazard model adequate for spatially distributed systems.

- **Develop a unified methodology to assess vulnerability at a system level.**
  A general methodology is proposed, to evaluate and quantify vulnerability and losses considering systemic interdependencies, which is further specified for each particular network.

- **Develop methodology and tools to assess the socio economic vulnerability and losses.**
  A methodology and tools to assess the socio-economic impacts due to seismic damages that influence preparedness and response activities in the context of short-term emergency relief and recovery (emergency shelter, health care facilities, transportation infrastructure, utility systems). Appropriate methodologies including indicator based systems for integrating socio-economic impacts with fragility functions and performance models.

- **Build an appropriate open-source software and tool to deal with systemic vulnerability.**
  An appropriate open source and unrestricted access software tool where the SYNER-G methodology and tools has been implemented.

- **Apply and validate the effectiveness of the methodology and tools to specific and well selected case studies at city and regional scale.**
  Verification of the systemic vulnerability and risk assessment approaches developed in SYNER-G through numerous applications at selected case studies at city scale (Thessaloniki, Vienna), regional scale (a transportation network in South North-Eastern Italy, an electric power transmission network in Sicily and a gas pipeline network in Central Italy) and in complex systems (the harbor of Thessaloniki and a large hospital facility in Reggio di Calabria, Italy).

  Propose guidelines and dissemination schemes for all products of the project.
  Several reference reports were prepared to use in practice and appropriate dissemination schemes at European and International level were built for the entire community and administration entities as well as insurance industry.

Project context:

SYNER-G proposes an integrated general methodology and a comprehensive simulation framework for the vulnerability assessment and the evaluation of the physical and socio-economic impact and losses of an earthquake, allowing also for consideration of multiple interdependent systems within the infrastructure. The end result is implemented into an open, modular and expandable software package for effective seismic risk management.

The concept of SYNER-G is to focus on systemic vulnerability assessment and seismic risk analysis of spatially distributed systems and infrastructures considering their distinctive European features, their inter and intra dependencies and including socio economic vulnerability and losses. SYNER-G provides a unified European probabilistic/ quantitative method for systemic physical vulnerability evaluation for buildings, lifeline networks, critical facilities and infrastructures to earthquakes. The project meets the expected impact by increasing understanding of vulnerability of various societal elements at risk, addressing inter-element and intra-system synergies, establishing a seismic societal vulnerability framework and specifying systemic vulnerability. An enhanced seismic hazard model for spatially distributed systems is developed and appropriate fragility functions are proposed for all elements at risk respecting the distinctive European features. A large number of case studies are included in the project for the demonstration and test the applicability of the proposed methodology and tools. Various dissemination activities, including a web portal, 7 reference reports, 3 technical workshops, numerous publications and presentation in conferences, transfer the latest developments to End-Users as well as to the scientific community. In this way, a valuable, powerful and innovative toolbox is provided to the decision-makers to assist the development of mitigation measures, while their implementation in practice is encouraged, contributing to changing the perception and confidence in risk management.
In particular the following results have been achieved:

Development of the general methodology

Development of the scientific basis for inter and intra-dependences for the vulnerability and loss assessment of complex interacting systems. A general methodology for systemic vulnerability analysis, including various aleatory and epistemic uncertainties has been developed. Performance indicators (PI) for systemic risk analysis have been defined and categorized. The typology/taxonomy for all elements at risk defined in SYNER-G has been carefully defined and practical means of data integration have been proposed and implemented. A prototype software (OOFIMS) has been developed using Object-Oriented Matlab platform where the methodology has been implemented and tested.

Seismic hazard
Seismic scenarios generation adequate for multi-system infrastructure risk analysis. This includes characterization of spatial correlation of single ground motion intensity measures and spatial cross-correlation of multiple intensity measures. Extension of the seismic input generation methodology to include geotechnical factors, such as site amplification of strong shaking and permanent ground deformation of slope displacement and liquefaction.

Remote sensing for systemic vulnerability analysis
Remote sensing and GIS data generation to be used for building inventories. A clear understanding of the applicability and potential limitations to the application of both airborne and space borne remote sensing data for deriving information pertaining to urban infrastructure. This includes automated derivation of road networks and extraction of key parameters relating to the geometry and typology of buildings within a region of interest.

Fragility curves for all assets
Selection of adequate fragility curves and functions and development of new ones, if needed, for all elements at risk, describing the systems of interest. A powerful fragility function manager tool (open source) for buildings and bridges has been developed.

Socio economic vulnerability and losses
Definition of socio-economic fragility and coping capacity indicators, data harmonization and benchmarking, definition of socio-economic impact models for Shelter Needs and Health Impact. Elicitation of importance weights for the selected indicators proposed for the shelter model based on the results of the literature study, the elicitation of weights for the indicators through statistical methods and deriving weights for the indicators based on a validation case study (L'Aquila). Development of a multi-criteria methodology and software tool for implementing shelter and health impact models considering all innovative aspect of SYNER-G. Development of health impact model extending the earthquake casualty estimation methods and linking with hospital functionality models based on a multi-criteria-analysis.

Systemic vulnerability
Specification of interdependencies between components of different systems namely system structure, represented by UML class diagrams, analysis levels and performance indicators. Each system has also been described using the object-oriented framework and represented with UML class diagram.

Applications and validation studies
Application and validation of the developed methods and tools in selected test sites: in city/ urban scale (Thessaloniki, Vienna), in network/regional scale (a transportation network, an electric power transmission network and a gas pipeline network in Italy), and in case of complex systems (the harbor of Thessaloniki and a hospital facility in Italy). For each system, selected Performance Indicators (PIs) are calculated based on the estimated damages and functionality losses of the different components. The overall performance of the network/infrastructure is expressed through the moving average μ and moving standard deviation σ (averaged over simulations), as well as the Mean Annual Frequency (MAF) of exceedance of the PIs. Maps with the distribution of estimated damages.

Prototype software
Fully functional open source software has been made freely available to the public. A comprehensive tutorial has been produced to allow handling and operation of the complex toolbox. The modular system contains input from all work packages and is held flexible enough to allow any future improvement. The software has been tested and its application successfully demonstrated.

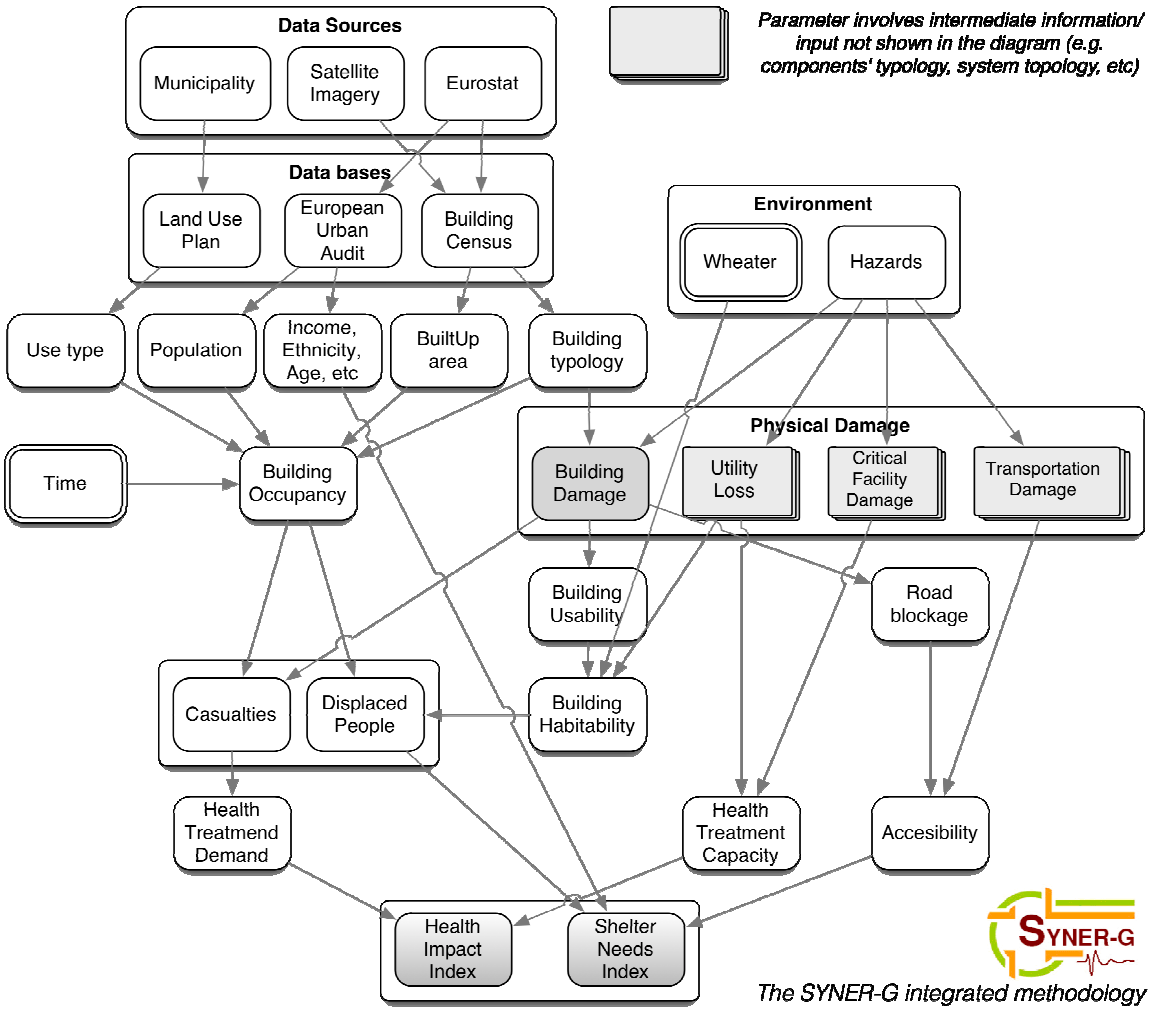
Dissemination activities
Dissemination of SYNER-G results to the scientific community, civil engineering society, public authorities and stakeholders through appropriate dissemination schemes including: project web server, seven comprehensive European Reference Reports, synthetic documents and deliverables, high quality brochure and leaflet, three technical workshops, a special session in the 15WCEE, peer review publications in journal and conferences, preparation of two books in Springer Editions.

Main S&T results/foregrounds

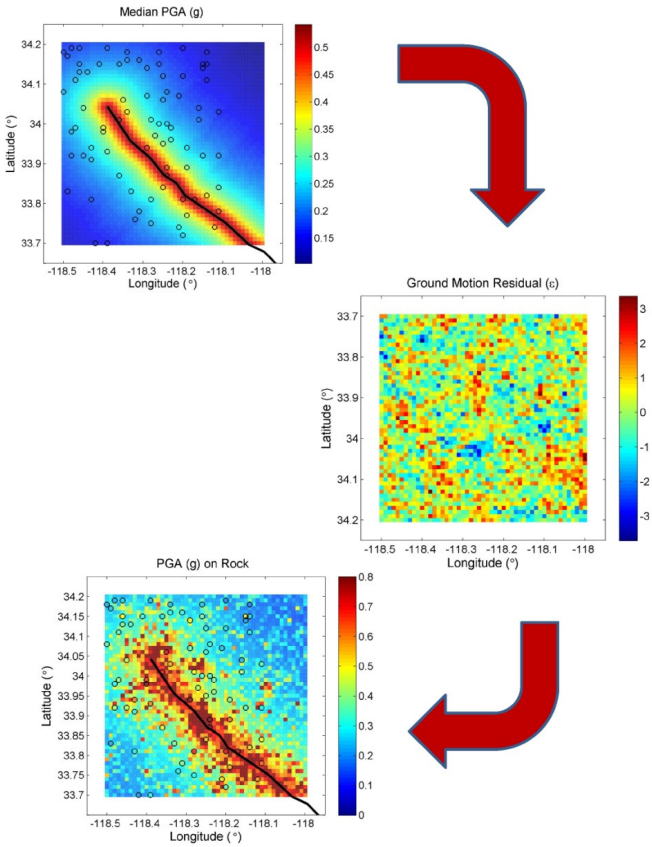
WP2: Development of a methodology to evaluate systemic vulnerability

WP2 has successfully undertaken a significant body of scientific and technological work that forms the fundamental basis for practical implementation of vulnerability analysis for multiple systems of inter-dependent infrastructures. The significant results of this project can be summarised as follows:

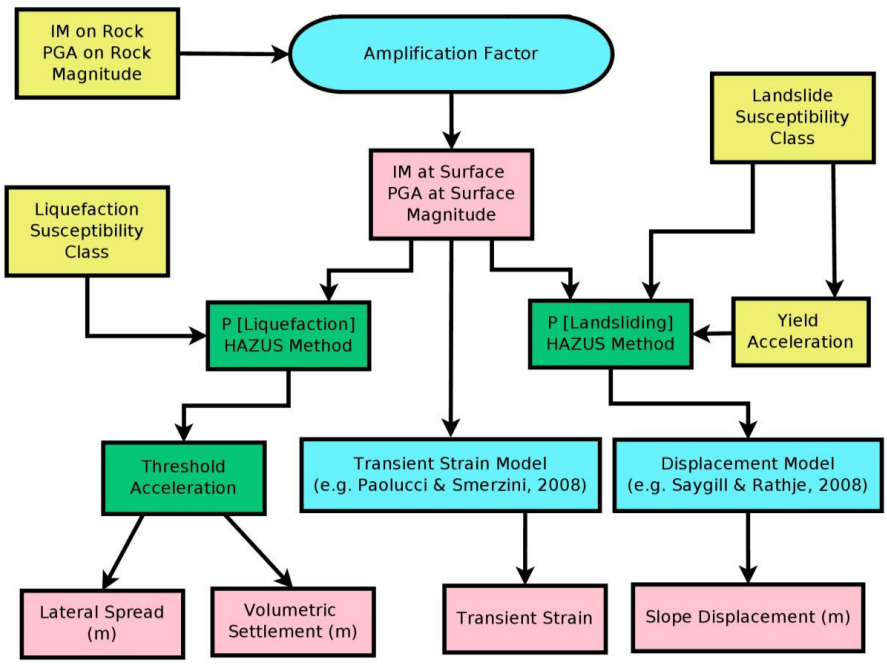
- The development of a crucial component of the scientific basis for the SYNER-G project through the development of a general methodology for systemic vulnerability analysis. This includes characterisation of uncertainties, both aleatory and epistemic, in the form of Monte Carlo simulations.
- The development of the prototype OOFIMS software programmed using Object-Oriented Matlab.
- The definition and categorisation of performance indicators for systemic risk.
- The definition of typologies of elements at risk within an infrastructure and the development of a practical means of data integration.



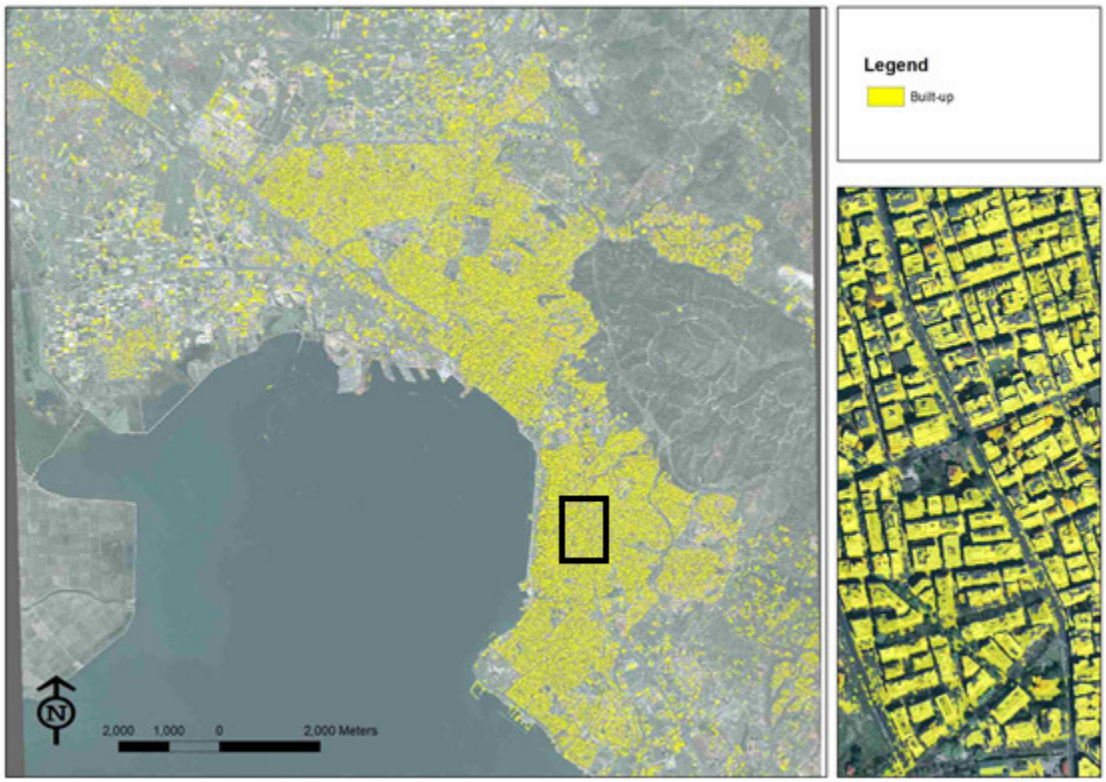
- The generation of seismic scenarios that are consistent with the practical needs of application to multi-system infrastructure risk analysis. This includes characterisation of spatial correlation of single ground motion intensity measures and spatial cross-correlation of multiple intensity measures.



- The extension of the seismic input generation methodology to include geotechnical factors, such as site amplification of strong shaking and permanent ground deformation of slope displacement and liquefaction.



- The integration of remote sensing and GIS data for developing building inventories needed for urban-scale seismic vulnerability analysis.
- A clear understanding of the applicability and potential limitations to the application of both airborne and spaceborne remote sensing data for deriving information pertaining to urban infrastructure. This includes automated derivation of road networks and extraction of key parameters relating to the geometry of buildings within a region.



WP3: Fragility functions of elements at risk

This work package focused on selecting and developing fragility functions for various elements at risk based on the taxonomy/typology that has been derived in the framework of WP2. The following four general areas of elements are considered: Buildings, utility networks, transportation network, and critical facilities. A literature review on the typology, the fragility functions (analytical/empirical/expert judgment/hybrid), damage scales, intensity measures and performance indicators has been performed for all the elements. The fragility functions are based on new analyses and collection/review of the results that are available in the literature. In some cases, the selection of the fragility functions has been based on validation studies using damage data from past and recent earthquakes mainly in Europe. Moreover, the damage and serviceability states have been defined accordingly. Appropriate adaptations and modifications have been made to the selected fragility functions in order to satisfy the distinctive features of the present taxonomy. In many cases new fragility functions have been developed based on numerical solutions or by using fault tree analysis together with the respective damage scales and serviceability rates in the framework of European typology and hazard. In addition, a Fragility Function Manager tool was implemented which compiles all the existing fragility functions for bridges and common masonry and reinforced concrete buildings in Europe in a database. This tool allows storage of new functions, visualization and harmonization of these functions for different parameters (Fig. 1).

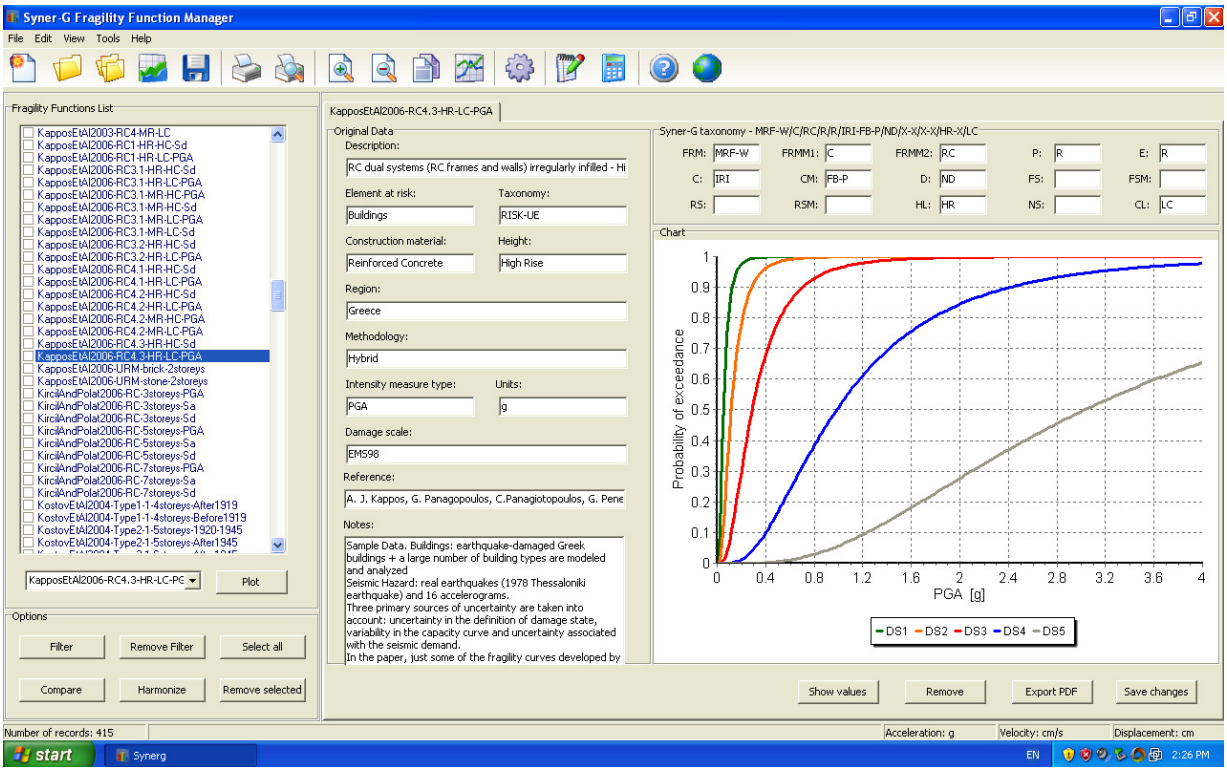


Fig. 1 Fragility Function Manager Tool

Fragility of buildings

An extensive literature review has been made which has led to a collection of fragility functions and identification of categories for grouping buildings (taxonomy) and for harmonising them based on different intensity measures and limit states. The main output is a set of fragility functions, with associated uncertainty, for the common typologies present in Europe. Finally, new approaches have been implemented for the creation of analytical fragility functions for reinforced concrete and masonry buildings in Europe.

Fragility of utility networks

A survey of the technical literature on fragility models for the components of electric power networks has been performed. This work has been carried out with the purpose of producing a state-of-the-art of the available models and indicating those that are most suited for use in the European context. The selection has been based both on the data supporting the models, when possible, and on the envisaged systemic approach for the simulation of EPN within the SYNER-G general methodology for infrastructural systems vulnerability assessment. The latter adopts a capacitive, detailed flow-based modelling with propagation of short-circuits over the network and requires internal modelling of the substation logic.

A literature review was performed, which concluded that the available fragility functions for the gas system elements are mostly empirical and should be applied to the European context, given the current lack of data needed to validate potential analytical methods of vulnerability assessment. For each network component (buried pipelines, storage tanks and processing facilities, including compression stations, pumping stations) appropriate fragility relations have been proposed together with typology classification of each component, damage scale definition and intensity measure. For specific components, like the Re.Mi cabins and GRF Reductions groups in the L' Aquila gas network, a fault tree has been formulated based on decomposition into the respective sub-components and the definition of the damage states.

A review of past earthquake damages on water and waste-water system elements was performed, including the description of physical damages, the identification of main causes of damage and the classification of failure modes. The main typologies of water and waste-water system components have been identified and the existing methodologies have been reviewed, including the damage states definitions, intensity indexes and performance indicators of the elements. The available vulnerability functions for pipes have been validated using damage data from recent European earthquakes (Düzce and Lefkas). In some cases, new fragility functions have been derived based on

fault tree analysis and the typological and fragility characteristics of the sub-components. Finally, appropriate vulnerability functions for all individual components have been proposed.

Fragility of transportation network

Literature review of existing fragility functions for bridges was performed and review forms were filled-in with information on the bridge typology, method of analysis, damage states and indicators, seismic intensity measures as well as type and number of accelerograms used in the analysis. Based on these studies, new fragility curves have been produced for European roadway and railway RC bridges. Regular bridges with continuous deck connected to the piers, either monolithically or through elastomeric bearings, have been studied. The examined parameters are: bridge length, number of spans, pier height and cross-section, number of columns per pier and level of seismic design. Two damage states have been examined: yielding and near collapse. Fragility functions have been constructed accounting for the model uncertainty for demand and capacity, the dispersion of material and geometric properties and the uncertainty of spectral values. Simple and efficient computer modules have been developed that construct quickly the fragility curve for a bridge, given its parameters. The numerical tools were also adapted for use in the Thessaloniki case study (WP6) by replacing the part of the code that performs the iterative design with one that allows to input the actual geometry and reinforcement details of specific structures and by updating the part that performs the assessment to accommodate different input data for each storey in buildings and for each pier in bridges.

A review of past earthquake damages on roadway elements has been made, including the description of physical damages, identification of main causes of damage and classification of the failure modes. The main typological features of roadway components have been identified and the existing methodologies have been reviewed together with damage states definitions, intensity measures and performance indicators of the elements. Empirical curves have been proposed for tunnels in rock and road pavements. Those for roadway pavements are validated based on damage data from recent earthquakes. New fragility curves have been developed for tunnels in alluvial, road on embankments, road in trenches and bridge abutments based on numerical analyses and use of PGA as the intensity measure. The analytical curves were tested against actual data of damages from recent earthquakes.

A review of past earthquake damages on railway elements was performed, including the description of physical damages, identification of main causes of damage and the classification of failure modes The main typological features of railway components have been identified, and the existing methodologies have been reviewed. Fragility functions have been proposed for all components, mainly based on those that are proposed for the roadway elements. For tunnels, the same fragility curves as for the roadway network have been proposed. For tracks on embankments, tracks in trenches and bridge abutments, the results of advanced numerical analyses of the corresponding roadway elements have been adapted to railway elements. In particular, new fragility curves have been developed considering appropriate threshold values for the definition of damage states. In case of tracks on slopes, the fragility curves for urban road pavements have been modified accounting for different threshold values.

Fragility of critical facilities

A review of past earthquake damages on harbor elements was performed including the description of physical damages, the identification of main causes of damage and the classification of failure modes. The main typologies for port components have been identified and the existing methodologies have been reviewed along with the damage states definitions, intensity indexes and performance indicators of the elements. Some of the empirical methods for waterfront structures have been validated using damage data from recent European earthquakes. New fragility curves have been developed for waterfront/retaining structures by using numerical analyses of typical cases. The corresponding damage levels are estimated with respect to the induced residual displacements and the seismic response of the soil-structure system. The new analytical fragility curves refer to the different types of waterfront structures and foundation conditions, taking also into consideration the aleatory uncertainties of the parameters involved. Finally, improved vulnerability functions, damage and functionality scale definitions have been proposed for all port components.

Literature review of fragility functions for hospital system, identification of the primary elements at risk in HCS including structural and architectural elements and equipment (operating theatres, medical gas supply systems, elevators, etc.), selection and adaptation of the fragility functions for these elements considering their distinctive European features, and harmonization of the fragility functions for their systematic incorporation in WP2 and WP5.

Literature review of available approaches for the seismic risk analysis of fire-fighting system, including available methods for the estimation of fire ignitions and fire spreading. The available approaches for the vulnerability analysis of the individual components are in line with those of the water supply system. In specific nodes of the system

(hydrants, buildings stations) proposals for their functionality assessment have been made using land use parameters and vulnerability (urban system, activities).

WP4: Socio-economic vulnerability and losses

The current state-of-the-art in earthquake engineering produces reasonably accurate estimates of physical damage to buildings and infrastructure systems as well as reasonable estimates of the repair and replacement costs associated with this type of damage. However, poor linkages between damage to physical systems and resultant social and economic consequences remain a significant limitation with existing earthquake loss estimation models. One of the main aims in SYNER-G, addressed in WP 4, was to develop a unified approach for modelling socio-economic impacts caused by earthquake damage which integrates social vulnerability into the physical systems modelling approaches. In SYNER-G, social losses (e.g., displaced population, shelter needs, health impacts) are computed as an integrated function of hazard intensity, systemic vulnerability of physical systems and the social vulnerability of the population at risk. This way of conceptualizing the integrated framework emphasizes the importance of understanding the interrelations between physical and social systems. In other words, how direct physical losses can potentially aggravate existing vulnerabilities in society and how vulnerabilities in society can ultimately lead to greater impacts from physical damage and losses.

Key outputs and scientific achievements of WP4 include:

- Development of a new semi-empirical Casualty Model: methodology, implementation and validation
- Development of a new Displaced Population Model: methodology, implementation and validation
- Development of harmonized, evidence-based socio-economic vulnerability and capacity indicators for Europe reflecting populations at risk of being displaced or in need of shelter.
- Development of harmonized, evidence-based socio-economic vulnerability and capacity indicators for Europe reflecting populations at risk of aggravated health impacts.
- Development of integrated GIS-based transportation accessibility models to shelter sites and healthcare facilities for effective emergency response.
- Development of a new multi-criteria decision model for the assessment of post-earthquake shelter demand
- Development of a new multi-criteria decision model for the assessment of post-earthquake health impact
- Development of an open source software tool and to capture post-disaster shelter needs decisions and interactions

The integrated approach proposed in SYNER-G provides a framework to link the degree of damage and performance of inter-related physical systems to vulnerabilities and coping capacities in society to assess: (1) Impacts on displaced populations and their shelter needs, and (2) Health impacts on exposed populations and their health-care needs. Furthermore, non-availability of lifeline networks (roads, pipelines, electricity and water supply) have important consequences on the recovery process and contribute to increased social disruptions within shelter and health sectors. In WP4 the impact of disruptions of the transportation system and utility systems on shelter and health systems is investigated. Emphasis in SYNER-G is placed on the early emergency relief and recovery period where the rapid provisioning of food, water, shelter and emergency healthcare services are the most important interventions to keep people alive and safe. Thus, the focus was on integrating models of social impact with loss estimation models for use in short-term emergency response planning.

Shelter Needs Model

Disaster displacement is a complex and dynamic process. Relationships between severely damaged and destroyed buildings and displaced persons after earthquakes in 457 earthquakes from 1900 to 2012 show a departure from linear relationships (assumed in state-of-the-art earthquake loss estimation models) representing coupled interactions between environmental, physical and socio-economic processes (Fig. 2).

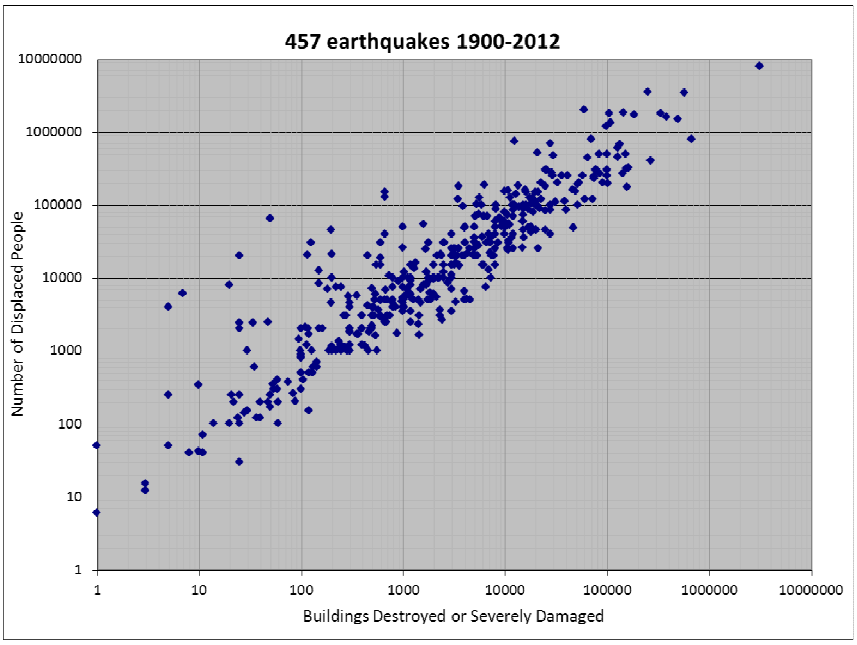


Fig. 2 Relationship between severely damaged and destroyed buildings and displaced persons after earthquakes (n = 457 earthquakes from 1900-2012 from the CATDAT database in Khazai et al. 2012

A new approach was developed for modelling emergency shelter demand by integrating shelter-seeking logic models into a systemic seismic vulnerability analysis and earthquake loss estimation software tool. Thus, the shelter model in SYNER-G provides a new advancement to shelter estimation methodology through three types of key inputs: (1) the "habitability" of buildings (defined by a households tolerance to the loss of power, gas and water for different levels of building damage and weather conditions) to provide information that can be used as a better determinant in influencing the decision of populations to evacuate than building damage alone; (2) GIS-based shelter accessibility analysis as an input to the shelter seeking model; and (3) complex socio-economic factors which represent the decision to evacuate and seek public shelter. These three inputs are combined into a dynamic shelter model which simulates a households' decision-making and considers physical, socio-economic, climatic and spatial factors in addition to modelled building damage states. The shelter model is implemented in the EQViz platform to provide stakeholders an interactive framework in decision-making process for shelter planning and preparedness.

The integrated shelter needs model developed in SYNER-G is based on a multi-criteria decision theory (MCDA) framework which allows the bringing together of parameters influencing the physical inhabitability of buildings, with social vulnerability (and coping capacity) factors of the at-risk population to determine as well as external factors to determine the desirability to evacuate and seek public shelter. As shown in Fig. 3, the multi-criteria framework can be described schematically as composed of the two main criteria: overall population at risk of being displaced after an earthquake (DPI), and the proportion of this population likely to seek public shelter (SSI). Subsequently, the total demand for public shelter for a particular location (i.e., city district) can be described as a product of the population at risk of being displaced (related to the occupants in uninhabitable buildings and their desire to evacuate or not) and a set of indicators determining the population likely to seek public shelter.

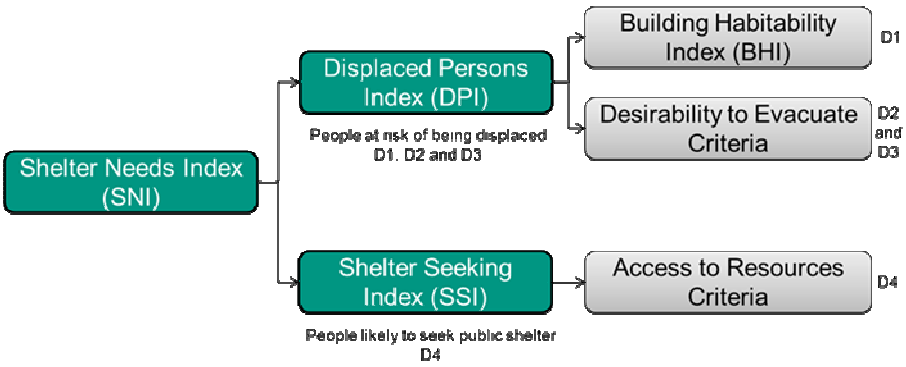


Fig. 3 Multi-criteria decision model for computing Shelter Needs Index (SNI)

To operationalize the shelter model, appropriate indicators from the EU Urban Audit Database have been selected using principal component analysis combined with expert judgment. Vulnerability factors deduced from the EU Urban Audit have been validated by applying the model using data from the M 6.3 earthquake that struck L' Aquila, Italy in April 2009. Fig. 4 shows how the modeling approach can be used to capture the actual shelter demand conditions (given as the observed number of people in shelter camps normalized by total population in different Mixed Operations Centres (COM) which had the overall coordinating role in their own territories for all rescue and shelter provision operations after the L'Aquila earthquake. Additionally, the shelter model was implemented in Thessaloniki where the systemic analysis for building and utility losses were brought together with socio-economic factors related to desirability to evacuate and seek shelter as „Hot Spots" for shelter needs using an interactive decision-support tool (Fig. 5).

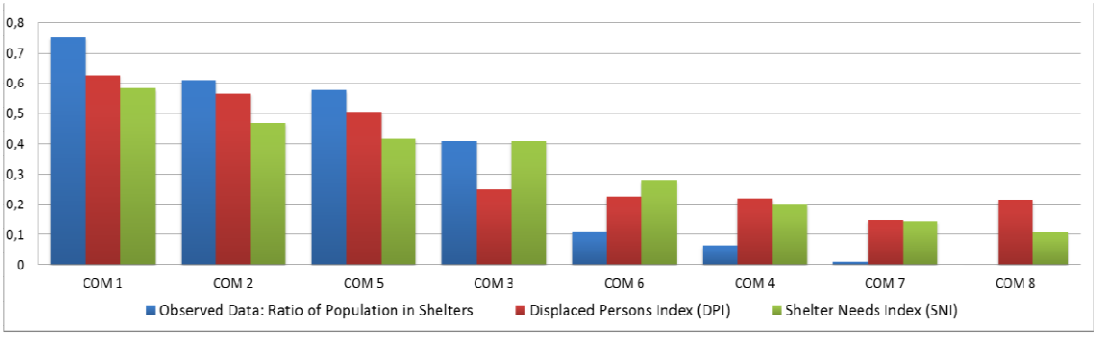


Fig. 4 Ratio of actual population in shelters (Observed data) shown against the ranking of displaced persons and shelter needs in the 8 COMs after the 2009 L'Aquila earthquake

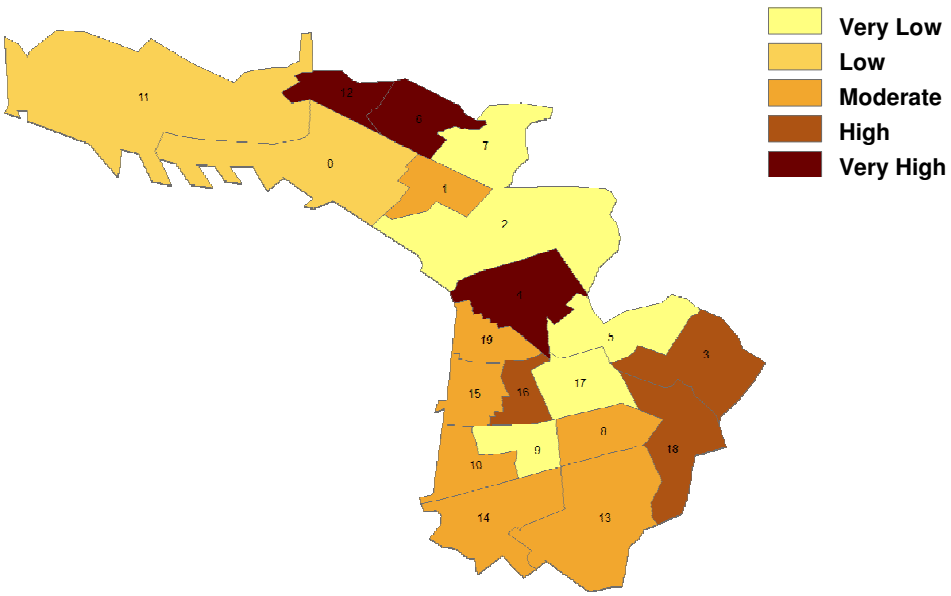


Fig. 5 Ranking of Shelter Needs Index (SNI) for sub-city districts of Thessaloniki

Health Impact Model

Similar to the shelter needs model, the health impact model presents a new method for integrating social vulnerability in modeling health impacts caused by earthquake damage. The health impact model is a function of casualties (number of dead and injured) produced by an earthquake and a number of impact factors that can aggravate health impacts further. First, a semi-empirical casualty model was developed in SYNER-G using a database for historic earthquake casualties collected for two large Italian earthquakes: Irpinia 1980, 214 municipalities and Friuli 1976, 26 municipalities. To link social impacts of health and health-care services to a systemic seismic vulnerability analysis, a multi-criteria decision model has been developed and appropriate social indicators for individual health impacts and for health care impacts were identified based on literature research, and tested using available European statistical data. The impact factors indicators developed are based on the following criteria: 1) social vulnerability factors which affect vulnerability and post-earthquake health of at-risk populations (e.g. demographic characteristics such as age, education, occupation and employment); 2) baseline health status factors (e.g. health expenditures, health care access, mortality, morbidity); 3) hospital treatment capacity factors and 4) environmental health factors (such as residential

crowding, sanitation, etc.). The results were used to develop a health impact model that describes the processes and links between socio-demographic, environmental, epidemiological and health behaviour parameters to increased short-term health impacts. Furthermore, healthcare systems parameters are integrated in a healthcare capacity model to assess secondary impacts on the overall health care delivery to the affected population.

WP5: Systemic vulnerability specification

Based on the general methodology developed in Work Package 2, each of the four systems considered in SYNER-G (Buildings and aggregates, utility networks, transportation networks and critical facilities) has been specified according to the features composing the SYNER-G approach:

- **Taxonomy** of the components within the system.
- **Solving algorithms** used to assess the system's performance.
- Nature of the **interactions** with components from other systems.

I. General specification

a. Taxonomy of components within each system

Following the framework of the general SYNER-G methodology, each class of systems is composed of sub-classes that are used to describe the various types of components, based on the geographical extent and their function within the system:

- **Cell classes** are used to define inhabited areas (i.e. Buildings System) and contain information on buildings typologies, population or soil occupation policy.
- All **network-like systems** (i.e. Water Supply, Electric Power, Gas Network and Road Network) contain two types of sub-classes (Edges and Points), which are further sub-divided in specific classes, according to the role played by the component within the system: network nodes can be stations, pumps, reservoirs, sources, distribution nodes, etc.
- For **critical facilities** such as components of the Health-Care System, they are modelled as point-like objects.

Each of the sub-classes is specified with their characteristic attributes and methods, depending on the type of system considered. For instance, initial properties of the objects may include geographic location, area, length, soil type, typology, associated fragility, capacity, connectivity with other components (for networks), etc. Once the simulation is running, the specific methods update the object properties, such as damage states, losses within each cell or remaining connectivity.

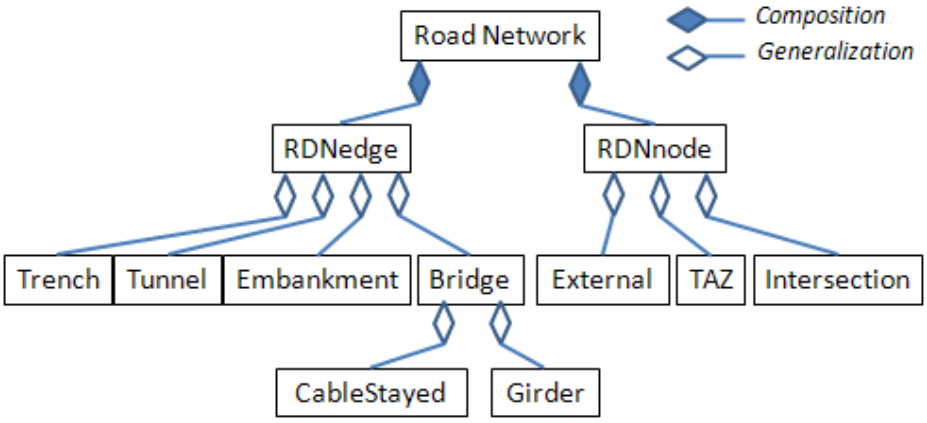


Fig. 6 Example of a specified UML diagram for the Road Network System

b. System evaluation and performance indicators

The way the performance of each system is assessed is also addressed in the work package. Three main types of solving algorithms are considered in the SYNER-G approach:

- **Connectivity analysis**: this approach removes the damaged components from the network and it updates the adjacency matrix accordingly, thus giving the nodes or areas that are disconnected from the rest of the system. This approach is used for all utility networks (water, electricity, gas) and the road transportation system.

- **Capacitive analysis**: for utility networks, graph algorithm can be used to optimize capacitive flows from sources (e.g. generators, reservoirs) to sinks (i.e. distribution nodes), based on the damages sustained by the network components (from total destruction to slight damages reducing the capacity).
- **Fault-tree analysis**: this type of approach aims to evaluate the remaining operating capacity of objects such as health-care facilities. The system is broken up into structural, non-structural or human components, each one of them being connected with logic operators.

Performance indicators, at the component or the system level, depend on the type of analysis that is performed: connectivity analysis gives access to indices such as the connectivity loss (measure of the reduction of the number of possible paths from sources to sinks). On the other hand, capacitive modelling yields more elaborate performance indicators at the distribution nodes (e.g. head ratio for water system, voltage ratio for electric buses…) or for the whole system (e.g. system serviceability index comparing the customer demand satisfaction before and after the seismic event).

c. Interdependencies

Three types of interactions between systems are considered within SYNER-G:

- **"Demand" interactions**: they correspond to a supply demand from a given component to another system. For instance, the presence of densely populated cells in the vicinity of a given distribution node (e.g. from a water supply or electric power system) will generate a substantial demand on the supply system. Another example could be the number of casualties that will put a strain on the treatment capacity of health-care facilities.
- **Physical interactions**: they are associated with exchanges of services or supplies between systems, like the supply of potable water to inhabited cells, the supply of transportation capacities by roads or the supply of power to various network facilities (e.g. water pumps) by electric generators.
- **Geographical interactions:** they are involved when two components are located in the same area and when the damage of one of them is directly influencing the physical integrity of the second one. For instance, the collapse of buildings in city centres can induce the blockage of adjacent roads due the debris accumulation.

The interactions between systems that are treated in the frame of SYNER-G are listed in the table below: **D** stands for Demand, **P** for Physical and **G** for Geographical interactions.

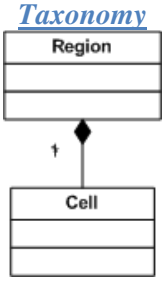
		BDG	EPN	WSS	GAS	RDN	HBR	HCS	FFS
Buildings	BDG		D	D	D	D G		D	
Power	EPN	P		P	P		P	P	P
Water	WSS	P					P	P	P
Gas	GAS	P					P	P	
Roads	RDN	P					P	P	P
Harbor	HBR								
Hospitals	HCS					D			
Fire Sys.	FFS								

It should be noted that the "demand" interactions are considered as static, since they are estimated only once, in order to avoid the presence of any feedback loops that would introduce dynamic systems, which are left of the SYNER-G scope. As a result, this table of interdependencies governs the order in which each system has to be computed during the simulation runs, in order to maintain a straightforward analysis scheme.

II. Description of the considered systems

a. *Building and aggregates*

Taxonomy



Performance indicators

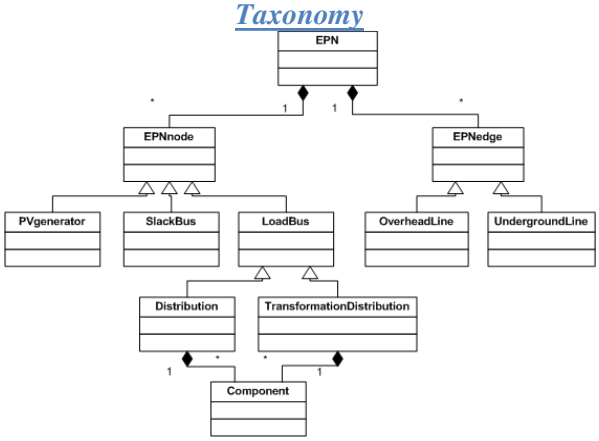
cell/*city*/*region*

Nb of yielding buildings
Nb of collapsed buildings
Utility losses
Accessibility losses
Habitability

b. *Utility Networks*

i. Electrical power Network

Taxonomy



Analysis

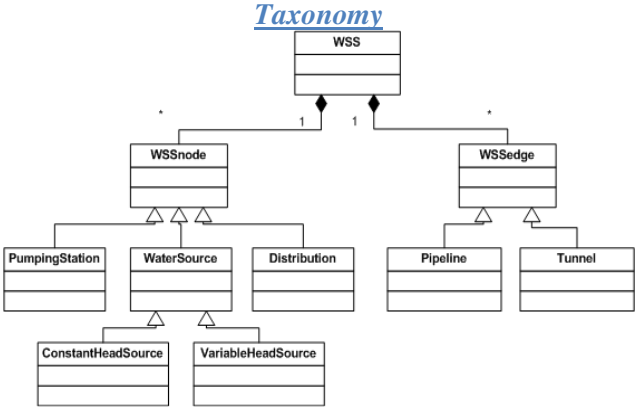
- Connectivity
- Serviceability

Performance indicators

- *Component:*
  Voltage ratio
  power ratio
  connectivity
- *System:*
  Average ratios
  Connectivity loss

ii. Water and waste water network

Taxonomy



Analysis

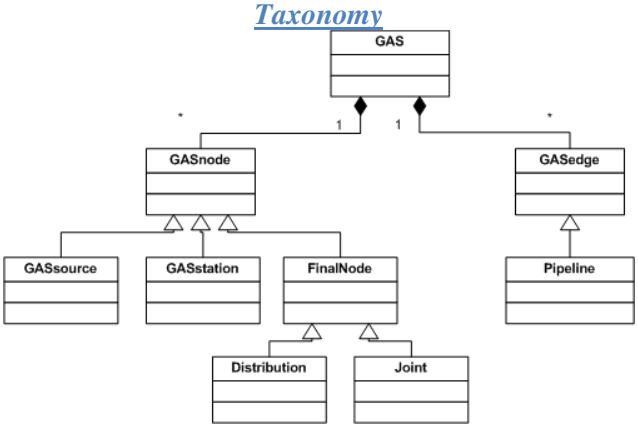
- Connectivity
- Serviceability

Performance indicators

- *Component:*
  Head Ratio
  Damage Consequence Index
  Upgrade Benefit Index
- *System:*
  Average Head Ratio
  System Serviceability Index

iii. Gas and oil Network

Taxonomy



Analysis

- Connectivity
- Serviceability

Performance indicators

- *Component:*

Head Ratio
Damage Consequence Index
Upgrade Benefit Index

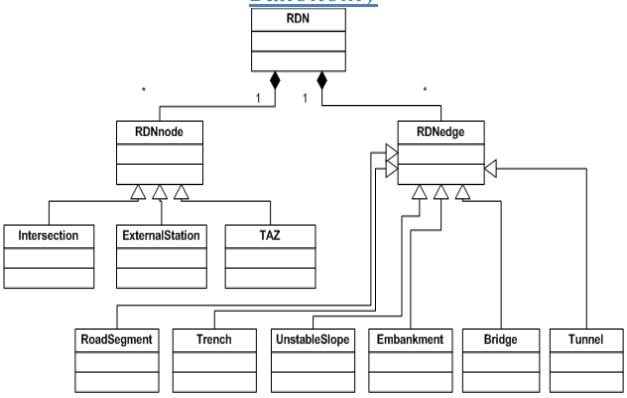
- *System:*

Average Head Ratio
System Serviceability Index

c. *Transportation network*

i. Road network

Taxonomy



Analysis

- Connectivity

Performance indicators

- *Component (Traffic Analysis Zone):*

Connectivity

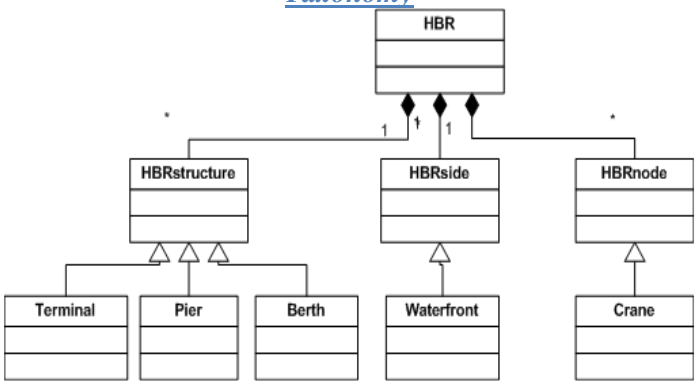
- *System:*

Simple Connectivity Loss
Weighted Connectivity loss

d. *Critical Facilities*

i. Harbour facilities

Taxonomy



Analysis

- Serviceability

Performance indicators

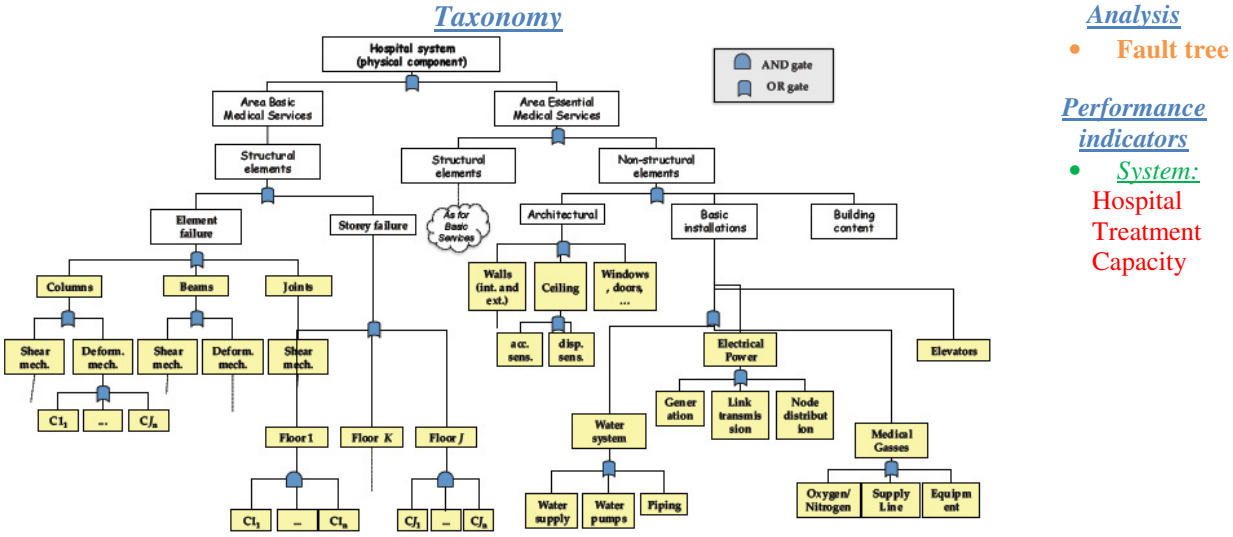
- *Component (terminal):*

Total Cargo handled

- *System:*

Total Cargo handled

ii. Health care system



WP6: Validation studies

The WP6 activities were dealing with the application and validation of the methods and tools that have been developed in WP2, 3, 4, 5 and 7 in selected test sites: in city/urban scale (Thessaloniki, Vienna), in network/regional scale (a transportation network, an electric power transmission network and a gas pipeline network in Italy), and in case of complex systems (the harbor of Thessaloniki and a hospital facility in Italy). The goal of the SYNER-G methodology, as demonstrated in the case studies, is to assess the seismic vulnerability of an infrastructure of urban/regional extension, accounting for inter- and intra-dependencies among infrastructural components, as well as for the uncertainties characterizing the problem. A probabilistic approach is followed which samples earthquake events based on the methods and tools developed in SYNER-G. Each sampled event represents a single earthquake (shakefields method) and all systems are analyzed for each event. The results are then aggregated all over the sampled events. In this way, all the characteristics of each event (e.g., spatial correlations) are accounted for and preserved for the systemic analysis. For each system, selected Performance Indicators (PIs) are calculated based on the estimated damages and functionality losses of the different components. The overall performance of each network is expressed through the moving average μ and moving standard deviation σ (averaged over simulations), as well as the Mean Annual Frequency (MAF) of exceedance of the PIs. Through the MAF graphs the annual probability of exceeding specific levels of loss can be defined and the loss for specific mean return period of the particular PI can be estimated. In some cases, correlation factors are estimated which relate the estimated damages of specific components with the system's functionality.
Maps with the distribution of estimated damages (and/or non-functionalities due to direct damage, inter / intra dependencies, or propagated mul-functionalities) are given as averages for all simulations.

Application and validation study in the city of Thessaloniki

The city of Thessaloniki in North Greece, is located in a high seismicity area. The study area covers the municipality of Thessaloniki which is divided in 20 Sub City Districts as defined by Eurostat and Urban Audit approach.

Fragility curves for buildings and bridges of Thessaloniki

New fragility curves have been developed for buildings (masonry, R/C) and bridges of Thessaloniki. Three-dimensional finite element analysis with a nonlinear biaxial failure criterion was used to derive fragility curves for masonry buildings that consider in-plane and out-of-plane failure (Fig. 7). Fragility curves for RC buildings that account for shear failure and consider model uncertainties and the scatter of material and geometric properties were produced following the assessment method of Eurocode 8. Results for wall-frame buildings are shown in Fig. 8, where the effect of design codes is evident.

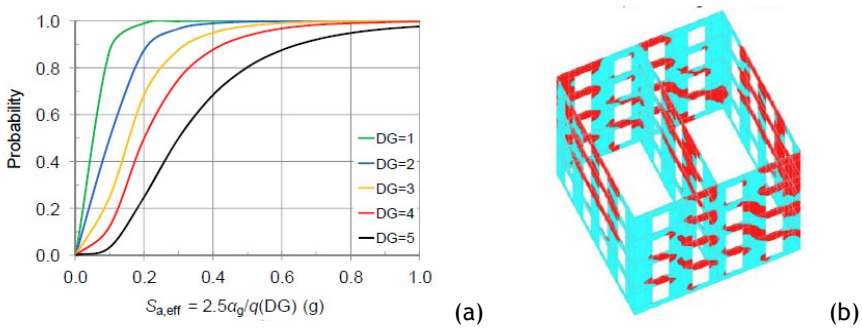


Fig. 7 Four-storey masonry building with flexible floors: fragility curves (a); analysis results showing out-ofplane damage (b)

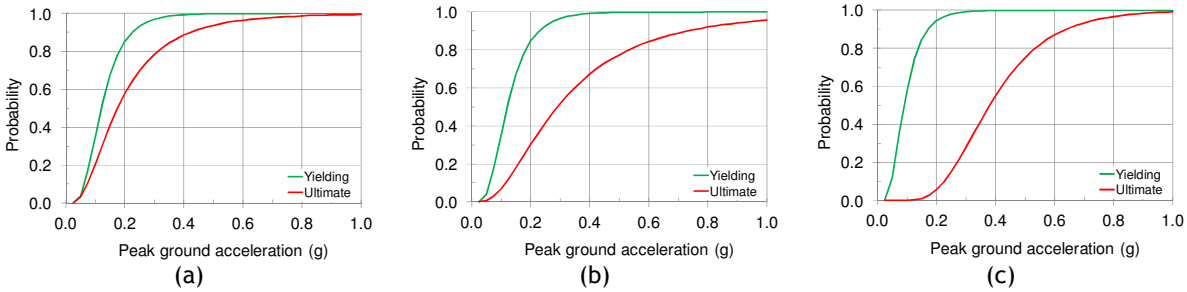


Fig. 8 Fragility curves for low-rise wall-frame buildings in Thessaloniki designed with low-level (a), medium-level (b) and high-level (c) seismic code

Analytical fragility curves were developed for specific bridges in the Thessaloniki study area, based on the available information about their geometry, materials and reinforcement. Older bridges are likely to experience damage for low to medium levels of earthquake excitation (e.g., Fig. 9a). On the other hand, modern bridges are markedly less vulnerable (e.g., Fig. 9b).

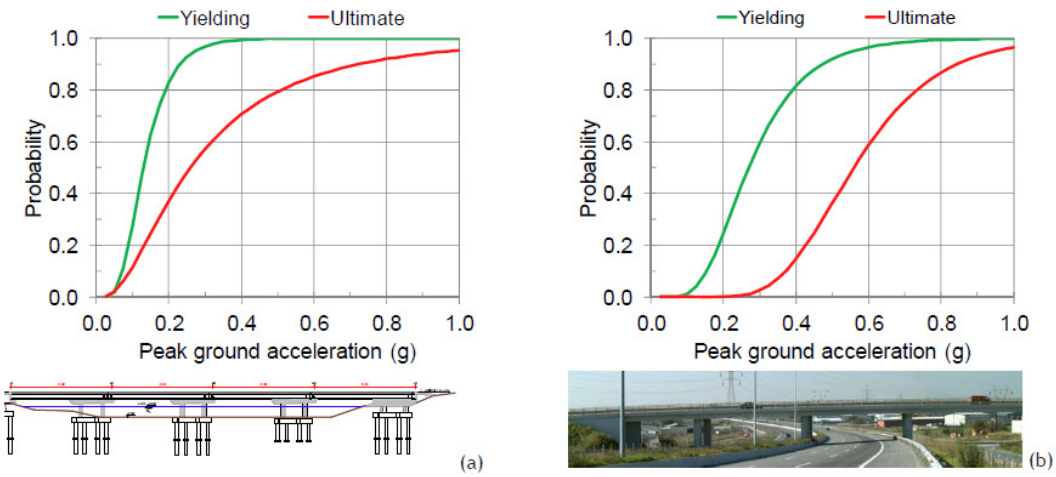


Fig. 9 Fragility curves for (a) a bridge with the deck supported on bearings, constructed in 1985 and (b) an overpass with monolithic deck-pier connection, constructed in 2003.

Thessaloniki case study

The case study includes the following elements: building stock (BDG), road network (RDN), water supply system (WSS) and electric power network (EPN). The networks are comprise by the main lines and components and cover the wider Metropolitan area. The internal functioning of each network was simulated and a connectivity analysis has been performed. Moreover, specific interdependencies between systems were considered: EPN with WSS (electric power supply to pumping stations), RDN with BDG (road blockage due to building collapses), BDG with EPN and WSS (displaced people due to utility loss). A Monte Carlo simulation (MCS) has been carried out (10,000 runs) based on the methods and tools developed in SYNER-G. The overall performance of each network is expressed through the Mean Annual

Frequency (MAF) of exceedance and the moving average μ and moving standard deviation σ of the PIs. Thematic maps showing the distribution of expected damages/ losses were produced for selected events. Moreover, the significant elements for the functionality of each system are defined through correlation factors to the system PIs.

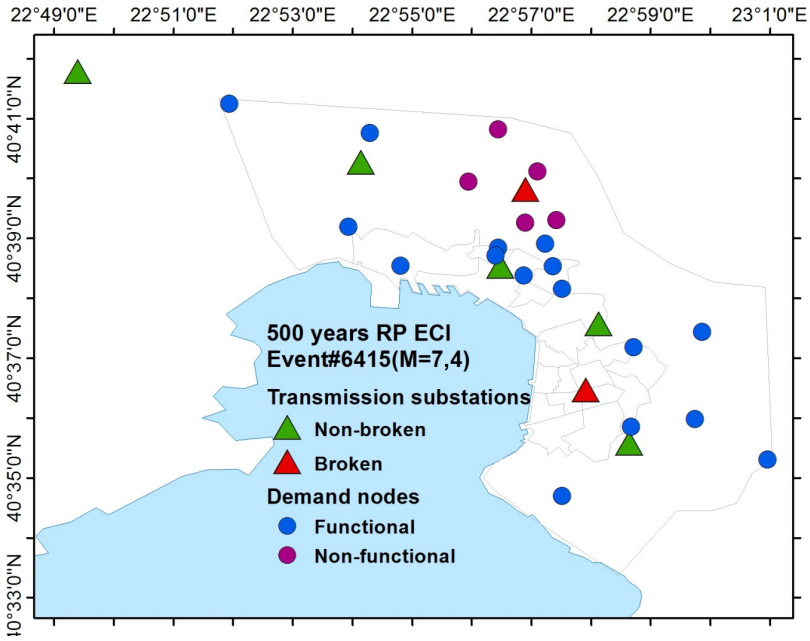


Fig. 10 Electric power network damages for an event (#6415 M=7.4, R=40km) that corresponds to ECL with Tm=500 years

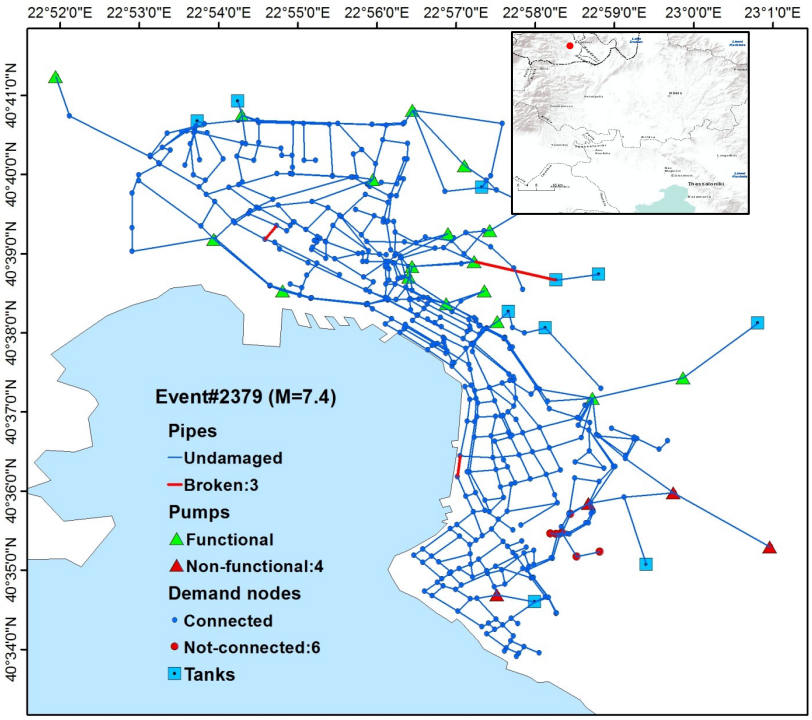


Fig. 11 Water supply system damages for an event (#2379, M=7.4, R=72km) that corresponds to WCL with Tm=500 years

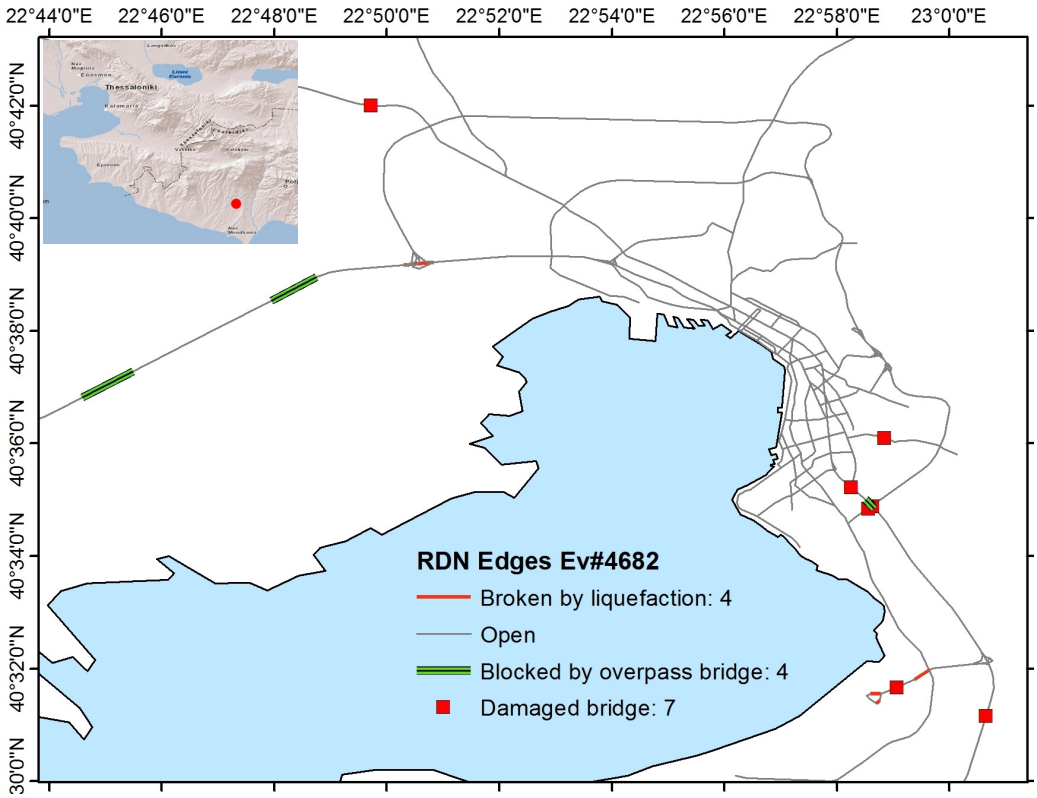


Fig. 12 Road network damages for an event (#4682, WCL=18%, M=7.4, R= 40 km) that corresponds to WCL with Tm=500 years

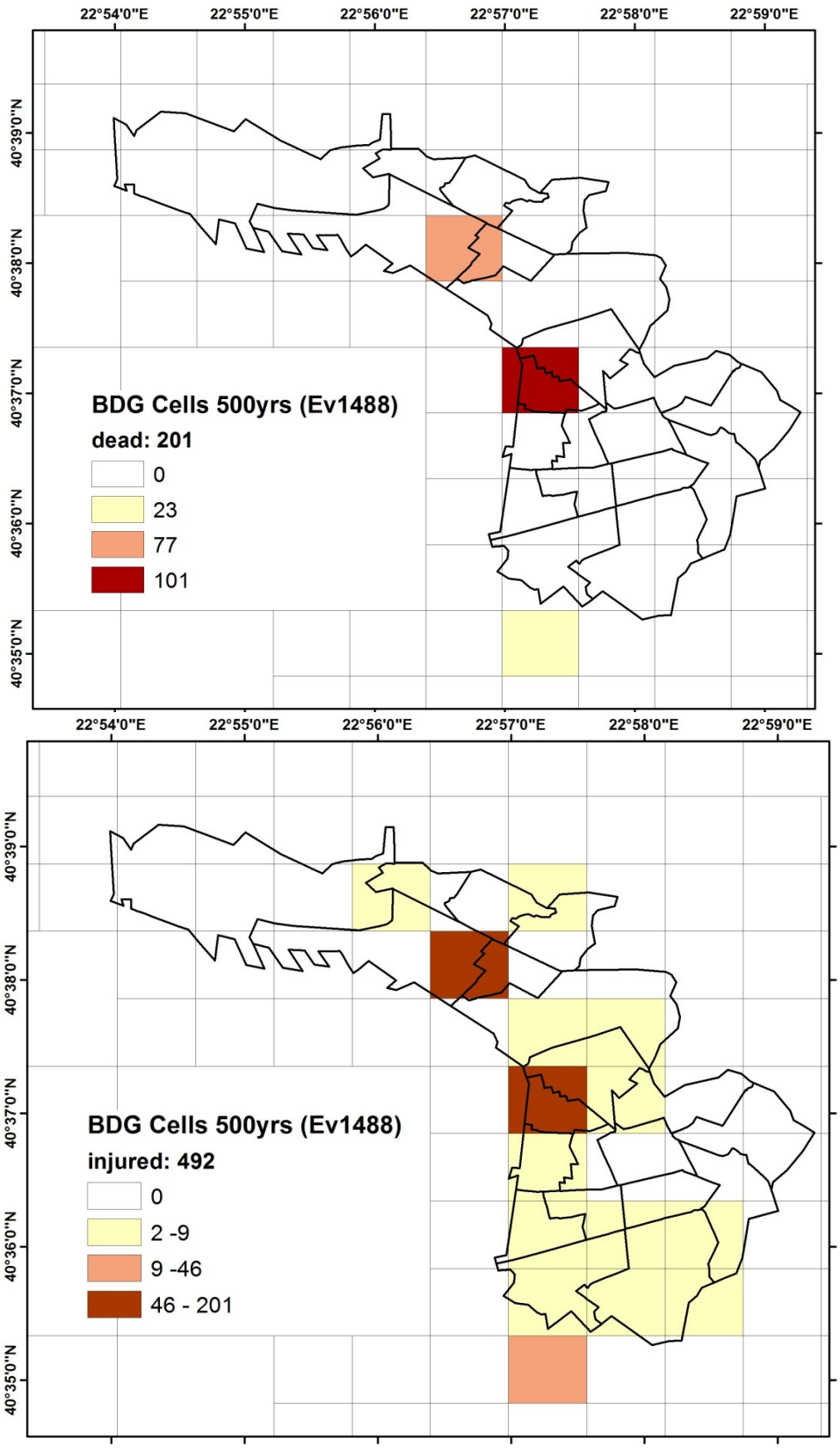


Fig. 13 Distribution of estimated casualties (deaths, injuries) into cells of the study area for an event (#1488, M=5.5, R=24 km) that corresponds to death rate with Tm=500 years

Shelter demand analysis

The estimated damages and losses for buildings, utility and road networks are used as input to the integrated shelter need model developed in SYNER-G (see WP4). In particular, a Shelter Needs Index (SNI) is estimated for each one of the 20 Sub City Districts (Fig. 5) based on: a) the displaced people estimates for bad and good weather conditions, which are a function of the building damages (BDG) and the utility losses (WSS and EPN), b) the desirability of people to evacuate and c) their access to resources. Criteria b) and c) are evaluated based on indicators from the Urban Audit survey (e.g. age, family status, unemployment rate, education level etc).

Accessibility analysis

The estimated damages and losses of the road network provided input for the accessibility modeling to shelters and hospital facilities using isochrone-based and zone-based techniques. An example is given in Fig. 14, where the accessibility to health facilities is estimated using the results of RDN over all runs.

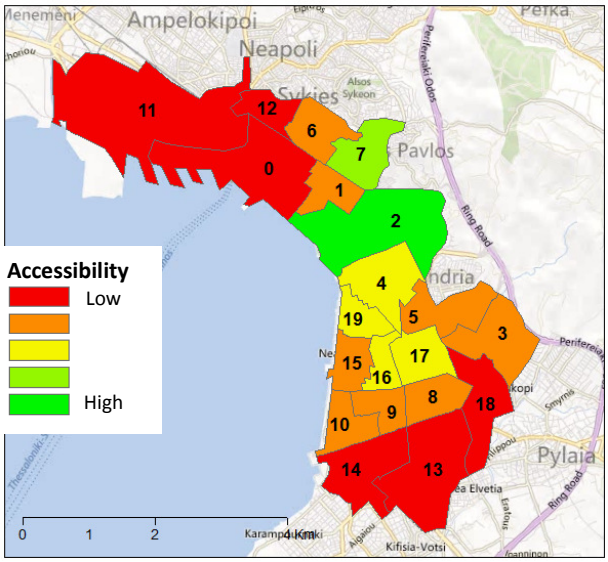


Fig. 14 Accessibility to hospitals for Thessaloniki SCDs (zone based technique)

Application and validation study in the city of Vienna

The city of Vienna in Austria, is located in a low seismicity area. The region of interest for the case study is the Brigittenau district, which is the 20th district of Vienna. A specific building identification procedure has been formulated to identify and inventory buildings that were considered in the case study. Both deterministic and probabilistic analyses have been performed. The EQvis software is used for the deterministic analysis, while the SYNER-G OOFIMSrunner performed the probabilistic analysis including buildings, water supply system, road and electric power network with specific interdependencies between them. A building identification procedure has been also formulated to identify and inventory buildings that were considered in the case study. Representative results are given in the next figures.

Fig. 15 Average blocked roads (left) and unusable ones (right)

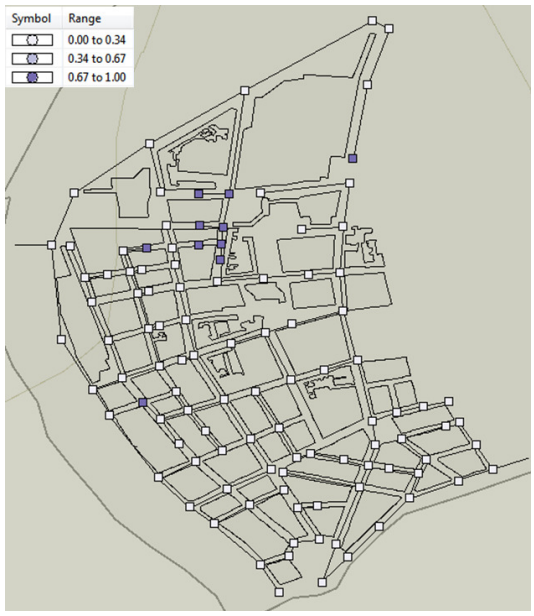


Fig. 16 Average damage on the electric power network nodes

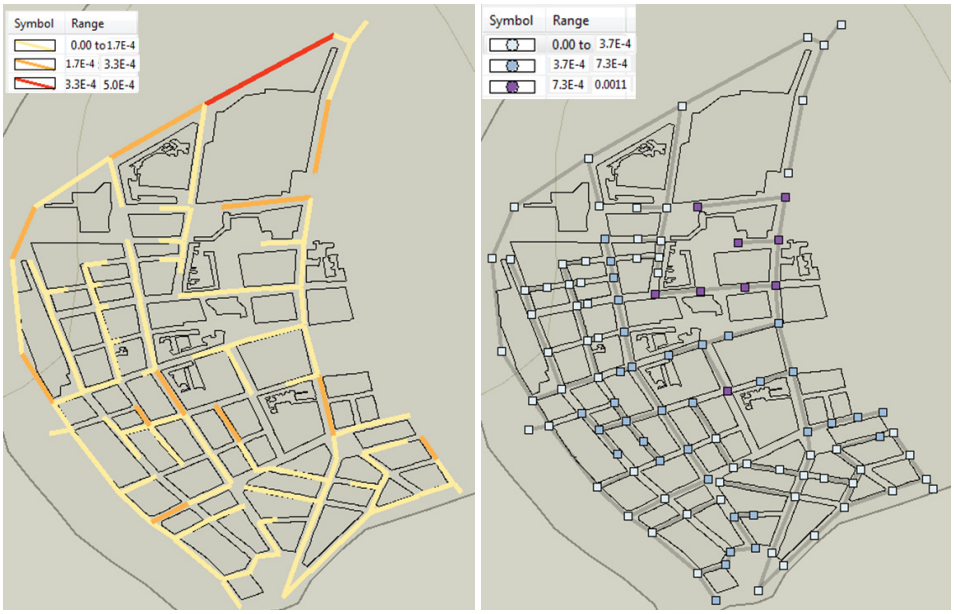


Fig. 17 Pipes broken (left) and non-functional nodes (right)

Application and validation study to a transportation network

The road network in Calabria region, Southern Italy was selected. A data reduction process was performed in order to remove the irrelevant components at the regional scale. A pure connectivity analysis is performed considering 2,861 nodes and 5,970 edges of the network. The seismic hazard is modeled through 20 faults taken from the Italian DISS database. Three types of simulation have been carried out: a plain Monte Carlo (MCS) and two improved simulations employing variance reduction techniques, i.e. Importance Sampling (ISS) and Importance Sampling with k-means clustering (ISS-KM).

As an example Fig. 18 shows the MAF of exceedance curves for SCL (Simple Connectivity Loss) and WCL (Weighted Connectivity Loss). As expected, weighting the computation of connectivity loss with the path travel times yields higher values of exceedance frequency. Fig. 19, left, shows the contour map of travel time to the closest hospital for the entire region, in non-seismic or undamaged conditions. The blue "islands", with zero travel time, clearly indicate the hospitals' positions in the region. Fig. 19, right, shows the contour map of expected travel time increment in damaged conditions, obtained dividing the expected value of minimum travel time in seismic conditions (averaged on the whole simulation) by the reference minimum travel time. Such increment results to be very low and concentrated in the central mountainous part of the region.

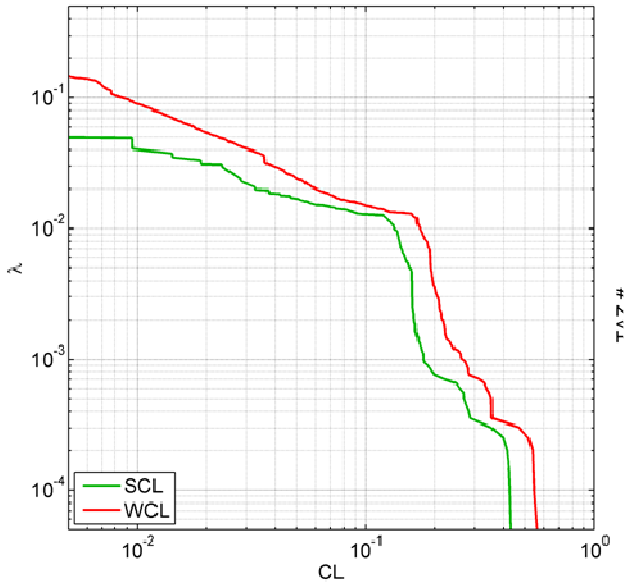


Fig. 18 MAF curves for SCL and WCL

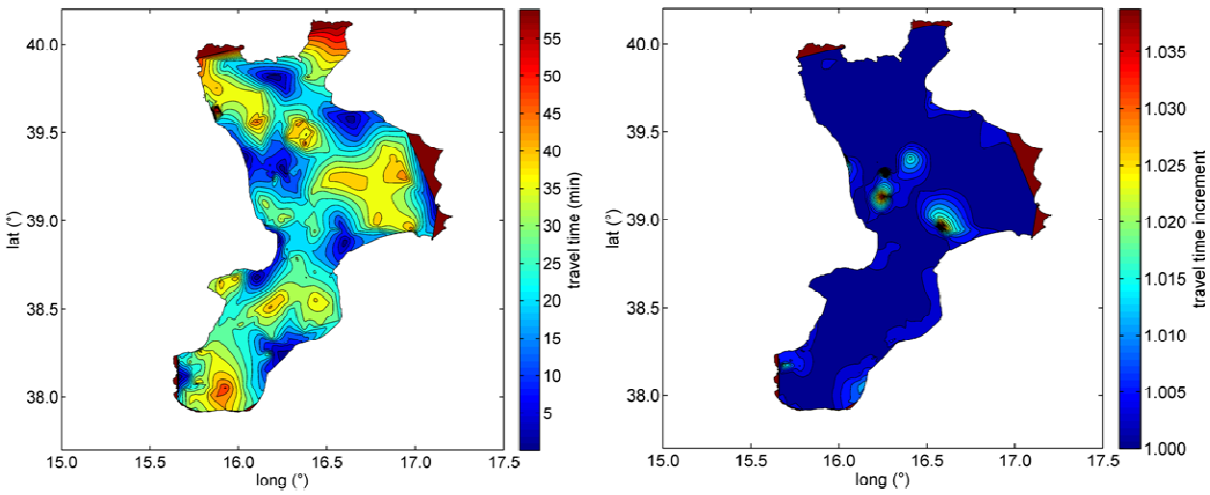


Fig. 19 Contour maps of minimum travel time to hospitals, in non-seismic conditions (left) and of expected increment of minimum travel time to hospitals (right)

Application and validation study to an electric power network

The electric power network of Sicily was selected. A capacitive study is performed, with power flow analysis that follows the analysis of short-circuit propagation, in which circuit breakers are active components playing a key role in arresting the short-circuit spreading. The substations are not modeled as vulnerable points; in fact, their full internal logic is modeled to account for partial functioning. The network is composed of 181 nodes and 220 transmission lines. The seismic hazard is modeled through 18 faults taken from the Italian DISS database. Three types of simulations have been carried out: a plain Monte Carlo (MCS) and two improved simulations enhanced with variance reduction techniques, i.e., Importance Sampling (ISS) and Importance Sampling with k-means clustering (ISS-KM).

Fig. 20 shows the MAF of exceedance curves for CL (Connectivity Loss) and SSI (System Serviceability Index). While the CL MAF presents a wide range of variation, SSI confirms to be a very stable indicator, with MAF values ranging in a small interval. Fig. 21 displays a contour map of the expected values of VR (Voltage Ratio), averaged on the whole simulation for each demand node. It can be seen that the reduction in voltage due to seismically induced damage is less than the tolerated threshold of 10%, allowing the power demand delivery everywhere in the island, consistently with the very large value of SSI and very low value of CL.

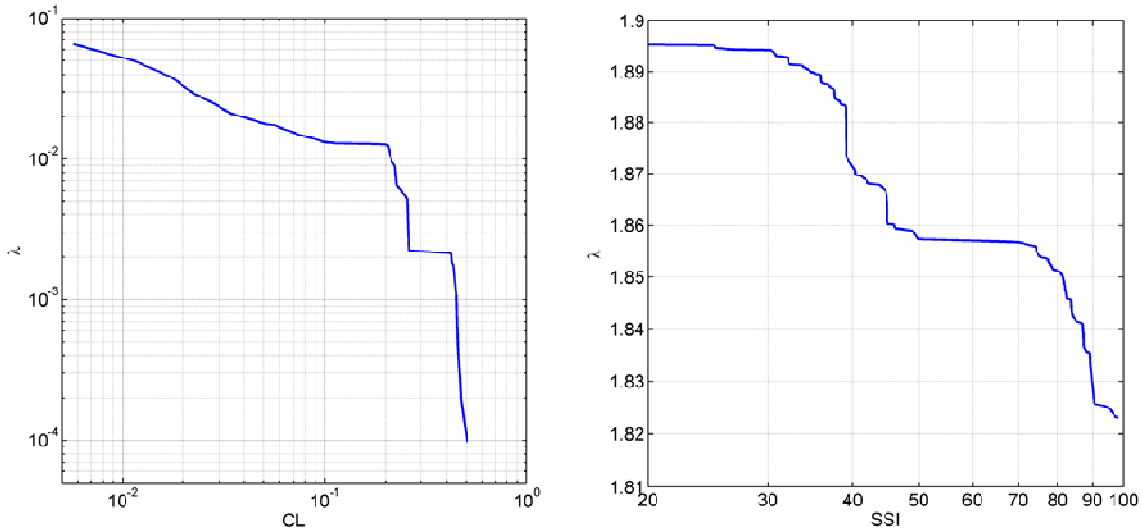


Fig. 20 MAF curves for CL (left) and SSI (right)

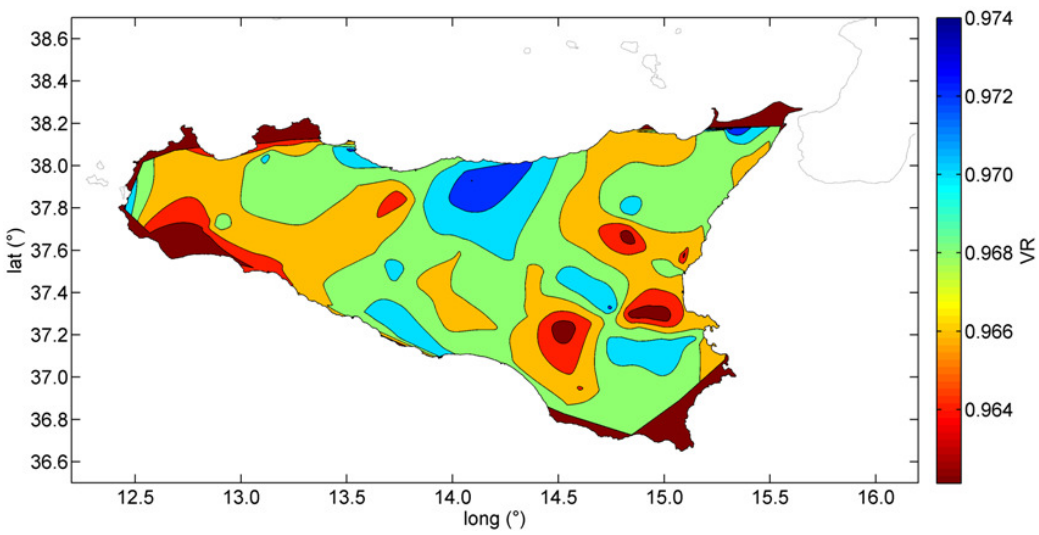


Fig. 21 Contour map of expected values of VR

Application and validation study to gas pipeline network of L' Aquila

The medium-pressure portion of the L'Aquila gas system was selected. It is characterized by 3 M/R stations, 209 Reduction Groups, and pipelines at medium pressure, either made of steel or high density polyethylene. The network is comprised of 602 nodes and 608 links. A connectivity analysis is performed considering ground shaking and ground failure due to liquefaction. The quantitative measure of the seismic performance is given by Performance indicators (PIs), that express numerically the impact of the earthquake on the systemic vulnerability, quantifying the degree to which the system is able to meet established specifications following a seismic event. Two PIs are used, the Serviceability Ratio (SR) and the Connectivity Loss (CL). A Monte Carlo Simulation (MCS) was carried out in order to evaluate the probability of exceeding a predefined level of performance, given the occurrence of an earthquake on the fault. Results indicate that the expected value of connectivity loss given the occurrence of an earthquake is 0.65, i.e., it is expected that the average reduction in the ability of demand nodes to be connected to M/R stations is of 65%. While for the SR indicator, it is expected that 68% of demand nodes receive gas accounting for the importance level related to the nominal flow of the demand nodes.

In order to evaluate the contribution of some components of the risk on the performance of the network, some variables computed during each run of the simulation were stored and analyzed. In particular regarding hazard, the percentage of sites vulnerable to PGD (i.e., the ratio between the number of pipes where a PGD

greater than 0 was occurred and the number of pipes located on sites potentially subjected to landslide) were saved, while in order to study the effects of the performance state of the components of the network, the number of broken pipes and damaged M/R stations were analyzed. Correlation coefficients between these variables and performance indicators were also computed in order to evaluate possible linear dependences. The values of variables that contribute most to given values of the network's performance were investigated through a disaggregation procedure. The distribution of the number of broken pipes, damaged M/R stations and the percentage of pipes vulnerable to PGD conditional to the occurrence of the two PIs were computed (Fig. 22).

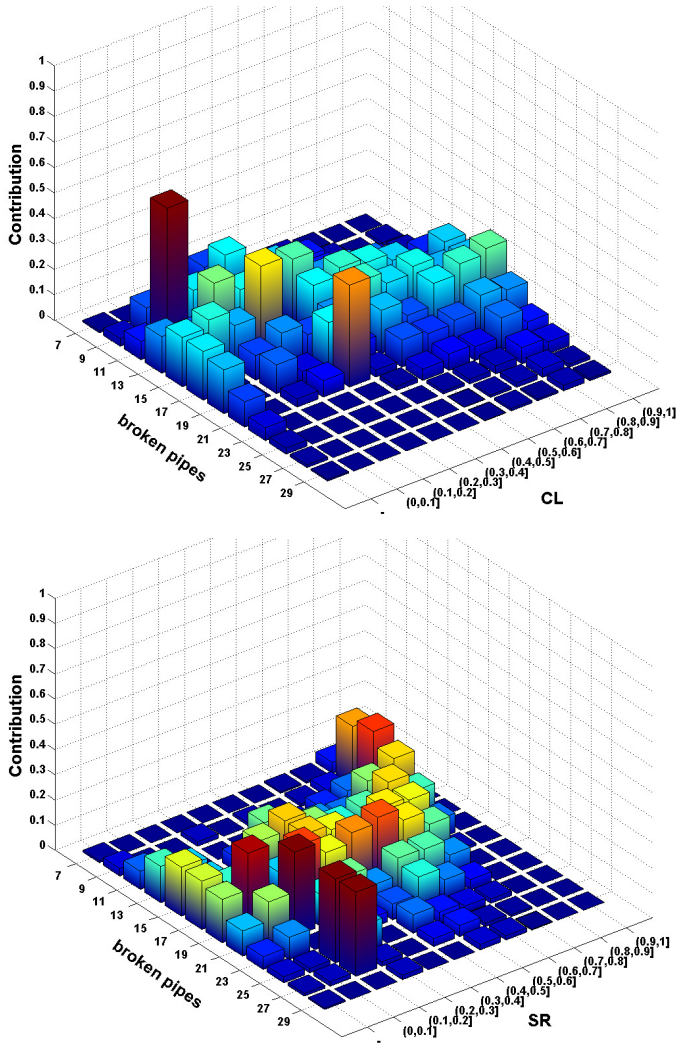


Fig. 22 Relative frequency of the number of broken pipes conditional to CL (top) and SR (bottom)

Application and validation study to harbour of Thessaloniki

The assessment of the systemic vulnerability of Thessaloniki's harbor is performed. The port covers an area of 1,550,000 m^2 and trades approximately 16,000,000 tons of cargo annually, having a capacity of 370,000 containers and 6 piers with 6,500m length. In the case study, waterfront structures, cargo handling equipment, power supply system, roadway system and buildings are examined. Following the methodological framework developed in SYNER-G for the simulation of port operations and the derivation of the system performance in case of earthquake events, waterfront structures, cargo handling equipment, power supply system, roadway system and buildings are examined. The main Performance Indicator (PI) used is the total cargo/containers handled in a pre-defined time frame per terminal and for the whole port system. The interactions considered in the analysis are the supply of EPN to cranes and the road closures due to building collapses. The correlation of damaged cranes and electric power distribution substations with

the PI TCaH (Total Cargo Handled per day) is given in figures Fig. 23 and Fig. 24. The dependence of the port performance over the functionality of electric power substations, and thus the supply of electric power, is highly stressed.

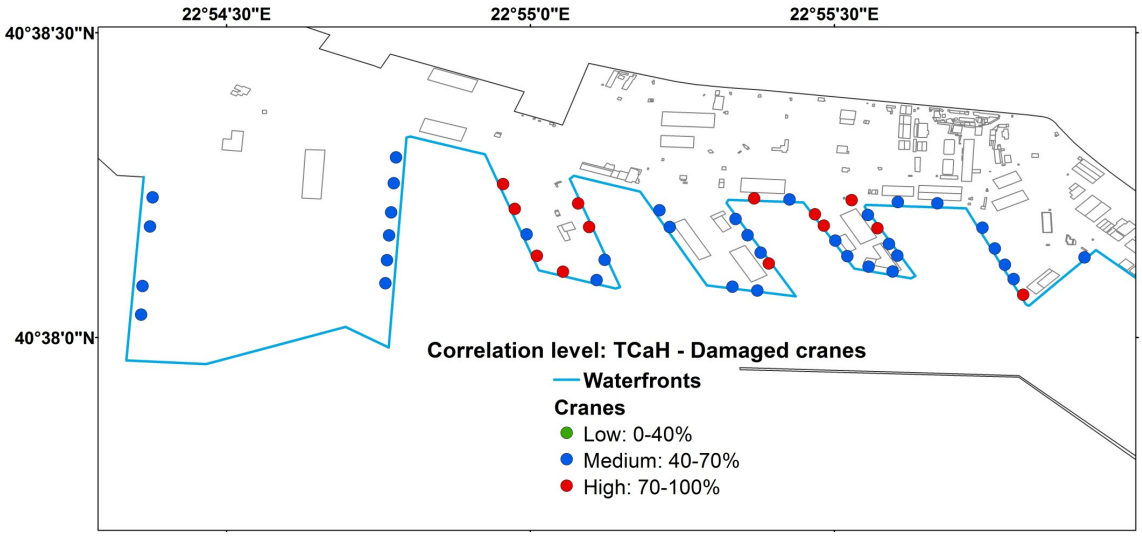


Fig. 23 Correlation of damaged cranes to port performance (PI=TCaH)

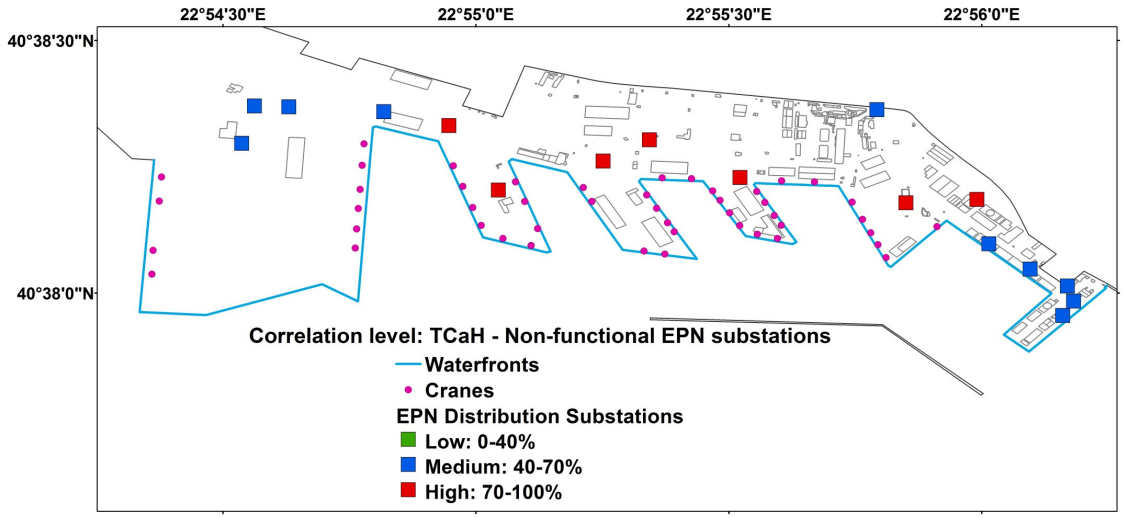


Fig. 24 Correlation of non-functional electric power distribution substations to port performance (PI=TCaH)

Application and validation study to a hospital facility and regional health-care system in Italy

The response of a regional health-care system is function of the hospital's performance but also of other factors, among which the response of the road network is of primary importance. In this case study the main goal is to forecast the expected impact in terms of: a) victims that cannot be hospitalised; b) hospitals that cannot provide medical care to the victims; c) city/villages that are not served by a functioning hospital within a "reasonable" distance.

The vulnerability assessment is based on a representative large medical centre located in south Italy, which should be able to provide all the "essential" medical services required to take care of the victims of a natural disaster under emergency conditions. Its design dates back to the end of the sixties. The facility consists of a main body composed of two separate RC buildings connected by two tower structures. The vulnerability of the facility is evaluated by non-linear dynamic analyses taking into account the response of structural as well as non-structural elements. The input ground motions are derived on the basis of a probabilistic seismic hazard analysis. Damages to the road network, and in particular to bridges, are also included. They affect the capability of transportation of the victims to hospitals, both by a reduction of the travel speed and by the

closure to traffic of the collapsed bridges. The number of victims is evaluated on the basis of demographic data by means of casualty models. The uncertainty in the estimation of victims is introduced in the analysis. The probability of HTC (Hospital Treatment Capacity)< HTD (Hospital Treatment Demand) is evaluated as function of PGA (Fig. 25). The convolution of this "vulnerability" function with the seismic hazard curve provides a measure of the global risk.

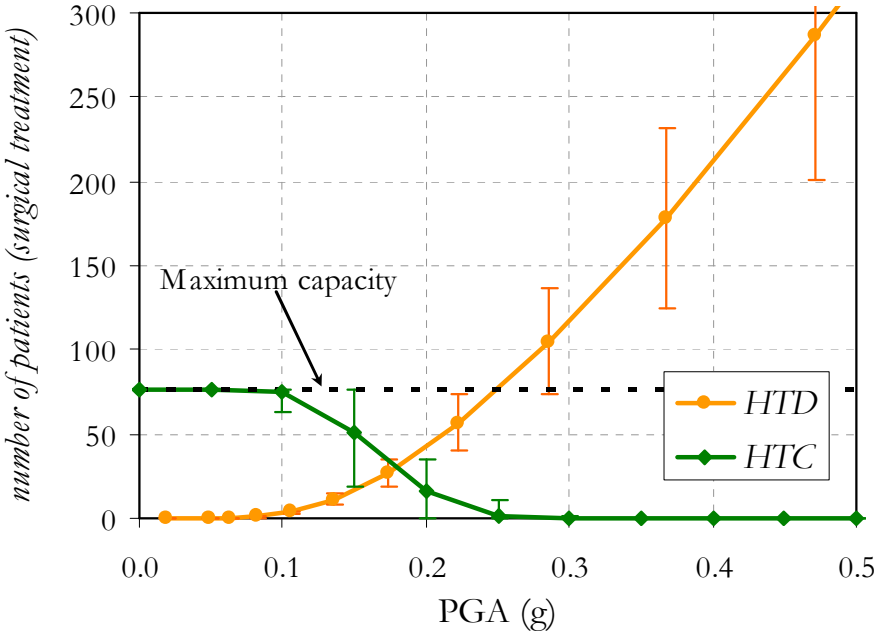


Fig. 25 Comparison of HTC and HTD

WP7: Build prototype software

A comparison of all available software packages has been done. There is a distinct favourite namely MaeViz which satisfies all the demands and has the benefit of having the creator within the consortium (U. Illinois). The entire open source software has been received and comprehensively tested. First test runs with real data have been performed to find out the capabilities. Information on the potential of the software has been given to the consortium several times to trigger the discussion on the prototype software for Syner-G. In task 7.1 all existing and developed fragility functions have been collected. In task 7.2 the introduction of this information into the future software has been started and is on the way. In task 7.3 the toolbox has been started and tried out on several occasions. In task 7.4 a workable dissolution for chew referencing has been fully implemented.

Based on the preparations performed in Period 1 a comprehensive tool box has been developed containing the research results of the project. The product EQvis (European Earthquake Risk Assessment and Visualisation Software) is an open source product that allows owners, practicing engineers and researchers the realistic risk assessment on systemic level. The software can be freely downloaded from the webpage (www.syner-g.eu) and comes with a comprehensive tutorial for easy handling.

In particular, the work performed in the Syner-G project was:

- Customising the existing software tools for the typical European conditions. This included branding as well as functional reshaping.
- Integration of the European fragility manager developed in work package 3 by partner UPAV into the EQvis platform.
- Integration of fragilities for roads, bridges, pipelines, electric systems, gas supply and water systems, power lines and substations and other utilities into the platform.
- Introduction of a distributed technology concept that allows the connection of individual modules in any of the elements of risk to the platform.

- Integration of the OOFIMS software module developed by URoma into the EQvis platform. This comprises a mechanisms that the OOFIMS module is handled by EQvis where in and output are generated and visualised.
- Validation of the development at several case studies on regional and building level. Particularity the Vienna test case has been used to try the functionalities, and the Thessaloniki test case for building aggregates.
- Development of a web based tool to define fragilities form input of web users only in combination with web based mapping services.
- Introduction of a module enabling the assessment of location based risk including its development over time (i.e. toxic gas distribution and progression)
- The open GIS interface has been considerably improved and enlarged. The latest IT-technology has been introduced
- In order to ensure sustainability of the software arrangement for use and further development after the end of the project has been made with the European project NERA (grant agreement number 262330) which will take over the software into its portal.
- The entire development work has reached a size where the means and manpower available in a small size project like Syner-G is not sufficient anymore. There is agreement that the next step of development should be done in collaboration with the ICT program in a large collaboration project.
- It has to be stated that the development work and the product available goes far beyond the proof of concepts and comprises already a solution ready for practice. Nevertheless the complexity and the knowledge required to utilise the full functionality restricts applications to the expert level.

Considering the progress described above the most significant results can be highlighted as follows:

- Fully functional open source software has been made freely available to the public.
- A comprehensive tutorial has been produced to allow handling and operation of the complex toolbox.
- The modular system contains input from all work packages and is held flexible enough to allow any future improvement.
- A very detailed Fragility Archive
- The software has been tested and its application successfully demonstrated.

Strong steps and commitments towards sustainability after the end of the project have been made to ensure the application of this development on global scale.

WP8: Guidelines, recommendations and dissemination

The JRC is Work Package leader of WP8 on Guidelines, recommendations and dissemination. The JRC coordinated the activities of WP8, maintaining constant contact with the partners participating in the work package, namely AUTH, VCE and UPAV, as well as with the editors and reviewers of the SYNER-G Reference Reports. The JRC participated to all the SYNER-G meetings and made presentations on the status of advancement and planned activities of the work package.

Writing, review and production of the reference reports

From the discussions at the 1st Annual Meeting, held in Vienna in 16-17 September 2010, a list of reports was set-up with proposed Editors and Reviewers. The process of writing (Template included) and Production of the Reports was agreed and communicated to the Editors and Reviewers of the Reports. The JRC prepared and distributed to Editors a template for collecting Version 1 of the Reference Reports (with structure, contents, and contributor partner). All responsible Editors prepared Version 1, which was sent for approval to the Reviewers.

Editors of the SYNER-G Reference Reports prepared a final draft collating the contributions from partners as identified in the Table of Contents of Version 1. The final draft was sent to reviewers, and the reviewed version was sent back to editors who prepared the final version that was then sent to the JRC. The JRC

made the final editing of the reports, including format, according to the guidelines prepared for the Reference Reports, and prepared the cover pages conforming to the JRC Scientific and Policy Reports. The JRC registered all seven Reference Reports at the JRC Publications Repository (http://publications.jrc.ec.europa.eu/repository). The Reference Reports will be printed by the JRC and are available online at the SYNER-G website.

Dissemination schemes for all products and tools

Development of communication, awareness and dissemination material and tools

Project web server

The JRC provided the main architecture of the document exchange platform, which was adapted by VCE for the SYNER-G project. The platform was fully transposed from JRC to VCE, who maintains and runs the platform. The address of the platform is https://www.syner-g.eu/login.php.

VCE prepared the public website of the project (www.syner-g.eu) that provides general, non-confidential information of SYNER-G to external users, such as key publications and deliverables, newsletters and announcement of meetings and workshops. The public pages of the website will be maintained through the NERA FP7 Project upon completion of SYNER-G.

Project leaflet

VCE developed a project leaflet, prepared and printed at the beginning of the project, containing a description, goals, objectives, and structure of the project, and a list of partners with their corresponding logos. The project leaflet was reviewed by AUTH, UPAV and JRC.

Project presentation

VCE developed early in the project a PowerPoint presentation, giving a summary, list of partners, background and overall objectives, goals, list of deliverables and main impact, dissemination of project results, management structure and procedures, and list of end-users. The project presentation was reviewed by AUTH and JRC.

Project newsletter

The project newsletter gives information on on-going activities of the project, on the outcome of past events and on the announcement of future ones. The first newsletter was issued at month 3, the second one at month 15 and the third one at month 27. The project newsletters were reviewed by VCE, JRC and UPAV.

Organization of project workshops

Technical Workshops in Thessaloniki and Vienna

Two technical workshops were organized during the last month of the project. The first workshop, titled "Seismic Vulnerability, estimation of losses and seismic risk assessment of the city of Thessaloniki in a potential future earthquake considering the interdependences between buildings, lifelines and critical infrastructures", was organized by AUTH and held in Thessaloniki on 1 March 2013. The second workshop, titled "SYNER-G: The Case Study in Vienna", was organized by VCE and held in Vienna at the VCE headquarters on 5 March 2013. The two workshops counted with the attendance of 130 and 55 participants, respectively.

Final Workshop

The JRC organized the final workshop of the project on 21-22 March 2013 at the NH Hotel President in Milano, Italy. The workshop counted with more than 60 participants from a wide representation of European

countries, partners of the SYNER-G project as well as from other institutions external to the project. The JRC invited to the workshop the members of the International Advisory Committee (IAC), and four more experts external to the project that delivered presentations and provided precious feedback and recommendations to the project.

Other awareness and dissemination activities

Booklets, leaflets and multimedia

Leaflets announcing the SYNER-G seminar at the 15WCEE, the two Technical Workshops in Thessaloniki and Vienna, as well as the Final Workshop in Milano were prepared by AUTH and VCE. A power point presentation presenting the use of the software tool in the form of a demo was prepared by AUTH.

Participation to Conferences and International Events

Partners of the project participated at the following main events: i) 14th European Conference on Earthquake Engineering, held in Skopje, FYROM, from 30 August to 3 September 2010; ii) Special Session "The benefits of standardisation in reducing seismic risk", as part of the 4th International Disaster and Risk Conference IDRC "Integrative Risk Management in a Changing World – Pathways to a resilient Society", held on 26-30 August in Davos, and iii) 15th World Conference on Earthquake Engineering (15WCEE), held in Lisbon, Portugal, from 24 to 28 September 2012, with special session (100 participants) organized on 24 Sept. describing the objectives and main outcomes of SYNER-G.

Publication of scientific results in peer reviewed journals, conferences proceedings and magazines

The partners of the project have successfully disseminated the results of the project during the first reporting period through the participation to Conferences, Seminars and publication in peer-reviewed Journals. A total of 9 peer-reviewed publications, 28 conference proceedings and 1 book have been published. Additionaly, 4 peer-reviewed journal articles are under review or print status. A detailed list of the dissemination activities is given in Tables A1 and A2 of the SYNER-G Final Report.

The project coordinator, Prof K. Pitilakis, was interviewed by the magazine Research Media Ltd (http://www.research-europe.com). A 3-page article titled "Assessing earthquake protection" was published and distributed to a list of stakeholders.

High Quality Brochure

A 76 page high quality brochure was prepared by JRC, collating and formatting the contributions from work package leaders. The brochure presents the main project products and the key results of the applications to the European urban, infrastructure and network sites. The brochure was distributed at the 15WCEE, at the two Technical Workshops in Thessaloniki and Vienna, and at the Final Workshop in Milano, and is available for download at the project website.

Involvement of potential users to achieve utilization

Identification of stakeholders and potential end-users

During the course of the project all partners contributed to identify and draw a list of stakeholders and potential end-users of the project knowledge and products. In all, 12 stakeholders from 7 different countries were identified. In addition to the list of stakeholders, the project maintained close contact with two important FP7 European Projects: SHARE and NERA. Through the first, SYNER-G gathered important information concerning a harmonized methodology for the definition of seismic hazard in Europe, while through the second project, SYNER-G will maintain its website and software tool developed in work package 7.

The project announced and invited to the Final Workshop held in Milano all stakeholders identified during the course of the project. Of these, a number of institutions external to the project attended the workshop, totalling 21 external to the SYNER-G project.

Collection and analysis of feedback from key events

In order to assess the quantity and quality of the information diffused in the Technical and Final workshops and to ensure that the information was useful and practical, participants were asked to respond to a questionnaire specifically developed for each of the workshops. The results indicate an overall quality of the workshop ranging from very good to excellent. The results are summarised in Deliverables D8.14 and D8.15. The questionnaires also contained optional questions answered in free format concerning recommendations for the project as a whole.

Development of detailed dissemination and exploitation plans

A detailed implementation plan for dissemination was prepared at month 12 and represents Deliverable D8.4, and was updated as synthetic deliverable (D8.18), summarize all the dissemination activities deployed during the life of the SYNER-G project.

The exploitation plan profits from the European Strategic Research Agenda on Earthquake Risk: Vision and Road Map for Implementation. It was presented and discussed during the Final Workshop and aims at setting up a scheme for continuous collaboration beyond the end of the project. This will allow advancing on research topics within the field of systemic seismic vulnerability and risk analysis, and to maintain and to further develop the tools developed during the project.

Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

Socio-economic impact and wider societal implications

The high seismic vulnerability of humans and built environment in Europe and the relative lack of appropriate mitigation programs, together with the overall moderate to high or very high seismicity resulted to significant direct and indirect earthquake losses in the past 30 years in Europe with a rapidly growing tendency. The vulnerability assessment methodology and the tools proposed by SYNER-G will have considerable impact on the seismic risk assessment and mitigation in Europe. The vulnerability assessment considering system inter- and intra-dependencies is in general higher than individual vulnerability of the elements within each system or even at a system. This new and advanced approach and products will help to apply mitigation measures in an optimized way, which can make them more effective for the society and the economy. Besides the reduction of loss of life and fatalities, the economic and social losses are expected to be considerably reduced.

SYNER-G will have impact at the following levels:

- Technology: A unique advanced European approach has been created which is well advanced with respect to other approaches available in USA and Japan.
- Society: The protection and safety of the population will be considerably improved.
- Economy: The results will enable to improve European building environment, infrastructures and lifelines, thus avoiding excessive losses from earthquakes to come. It will also bring European know-how at a leading position in this field.
- Standards: A standard modular methodology has been created allowing a European approach to the subject and allowing application all over the continent and enabling the construction industry to improve the built infrastructure and the risk assessment of complex industrial facilities and infrastructures.
- ERA: The European Union will be enabled to implement greater economic integration with its neighbours and internationally who are also considerably in need of these new methodologies.
- International Collaboration: The results of the project will make collaboration with Europe more attractive in particular for the USA, Japan, China and India. Europe will be enabled to take the lead on this subject.
- Technology Transfer: Europe will be seen as enabling the rising problems of mega cities in earthquake prone areas.

In particular, the main results of SYNER-G will have the following impact:

- The proposed unified advanced methodology for the systemic vulnerability and loss assessment of buildings, utilities, transportation networks and critical facilities due to seismic hazard at a European level, will help policy-setters and decision makers to optimize urban development and infrastructure planning and the efficiency of seismic risk mitigation strategies.
- The advanced methods and software tools for systemic seismic vulnerability and loss assessment of buildings, lifelines and networks will provide an increased understanding of the combined vulnerability of various societal elements at risk, including the inter-element and intra-system dependencies, which generally increase vulnerability and losses. The efficiency and applicability of the tools have been tested through appropriate case studies at European level.
- The fragility functions for all elements at risk considered in SYNER-G are a key step for the whole methodology, considering the specific typological features of European elements at risk and systems.
- Production of seven comprehensive reference reports constitute a European reference world-wide. They will provide guidance to stakeholders on where to direct research and development efforts and

to allocate resources where uncertainties need to be reduced or where cost-effectiveness can be increased.

- Reports and guidelines on innovative and state of the art methods and software produced within SYNER-G, will provide the roadmap beyond the state-of-the-art in lifeline earthquake engineering research, and a benchmark for future research in the field.
- The establishment of links and collaborative research between the engineering community (universities, research institutes and centres, private companies) and the insurance industry will lead to significant developments regarding the financial and social losses due to earthquakes, and facilitate direct output to interested stakeholders with an immediate impact for decision makers and policymakers.
- The various dissemination activities and the web portal, together with the reference and other reports have been the instruments to disseminate the latest developments in lifeline risk assessment and management and the proposed approaches and tools. In this way, a valuable toolbox is provided to the decision-makers to assist the development of mitigation measures, while their implementation in practice will be encouraged, thus again contributing to changing the perception and confidence in risk management.

Main dissemination activities

The partners of the project disseminated the results of SYNER-G through a dedicated program established at the start of the project (D8.4) and updated all through its completion (D8.18). A graphical representation of all dissemination schemes is given in Fig. 26. The activities for dissemination are given in the following list:

- Publication of Seven Reference Reports (Fig. 27), documenting the methods, procedures, tools and applications developed in SYNER-G. The list of the Reference Reports, with its corresponding editors, reviewers and address audience, is given in Table 1.
- Development of a website platform for the project set up early in the project, providing general, non-confidential information to external users, such as key publications and deliverables, newsletters and announcement of meetings and workshops (Fig. 28). The address of the home page of the public website is www.syner-g.eu.
- Preparation of a Project Leaflet (Fig. 29) and a Project Presentation (Fig. 30), prepared at the beginning of the project.
- Issuing of three Newsletters, at month 3, 15 and 27 (Fig. 31)
- Organization of two Technical Workshops, the first in Thessaloniki (1/3/2013) (Fig. 32) and the second on Vienna (5/3/2013) (Fig. 33), presenting the case studies for these two cities.
- Organization of the Final Workshop in Milano (21-22/3/2013) (Fig. 34), with the participation of the International Advisory Committee and invited experts.
- Preparation of a demo explaining the use of the software tool (Fig. 35)
- Participation at key events and Conferences, in particular: i) 14th European Conference on Earthquake Engineering, held in Skopje, FYROM, from 30/8 to 3/9/2010; ii) 4th International Disaster and Risk Conference IDRC "Integrative Risk Management in a Changing World – Pathways to a resilient Society", held on 26-30/08/2012 in Davos, and iii) 15th World Conference on Earthquake Engineering (15WCEE), held in Lisbon, Portugal, on 24-28/9/2012, with a special session organized on 24/9 describing the objectives and main outcomes of SYNER-G (Fig. 36).
- Publication of scientific results in peer reviewed journals, conferences proceedings and magazines, including an article on "Assessing earthquake protection" in the magazine Research Media Ltd (http://www.research-europe.com) (Fig. 37).

- Production of a 76 page High-Quality brochure describing the main project products and the key results of the applications to the European urban, infrastructure and network sites (Fig. 38).

Exploitation of results

In the following are summarized the main issues and recommendations gathered from the various discussions and interventions at the Final Workshop of the project:

- The definition of the taxonomy of elements at risk was one of the main outcomes of the project. However, for several elements, especially those of complex networks (e.g. industrial facilities), it will be necessary to extent the taxonomy and define appropriate fragility curves. It was also suggested to start working towards the production of European guidelines on taxonomy, with a possible view for future standardization. It was suggested to seek interaction with the INSPIRE Directive.
- In Horizon 2020 the issue of seismic and single natural risk may have a reduced importance with respect to FP7, with a shift towards multi-hazard risk and energy issues. It is important that the consortium and the scientific community as a whole explore ways on how to respond to the evolving needs of the society. The JRC proposed to combine seismic retrofit with energy upgrading, analysing the impact of different options in economic terms.
- To this end (Horizon 2020) the Strategic Research Agenda on Earthquake Risk should be updated with contributions from SYNER-G and other on-going EU projects, as well as from the seismologists' community.
- The consortium should improve the communication of results to stakeholders, shifting from the impact of an earthquake event to the impact of mitigation measures. It is important that the scientific community does not promise zero losses, but rather a reduction of risk through constructive suggestions and recommendations.
- The active participation of stakeholders in future applications is essential for the improvement of results and for more practical use of outputs. It is also important to make the results more accessible and easily understood to the wider community of potential end users. For example the use of average values over a large number of Monte Carlo runs was questioned, as it does not provide a physical quantity that can be communicated to stakeholders. The homogeneity and clarity of the various presentations of the results of the applications is necessary to this extend.
- The SYNER-G software and tools (pre and post processing) needs to be upgraded and further improved in order to be more "friendly" to end-users as well as to improve its computation performance.
- SYNER-G presented the state-of-the-art in systemic risk. It was questioned, however, that the method, as it is proposed, is far more detailed than the level of data available (elements at risk, fragility curves). Therefore, it is necessary to invest in data mining to refine the inventories of elements at risk we have today. It is also necessary to invest more to quantify better the effects of various uncertainties, including the available data, in the accuracy of the results.
- Other issues discussed: The SYNER-G webpage will run for the next two years under the NERA platform. Then a more permanent administration mechanism should be proposed. The SYNER-G DEMO will be prepared after the final reporting under the coordination of AUTH and VCE; JRC will contribute to its dissemination.

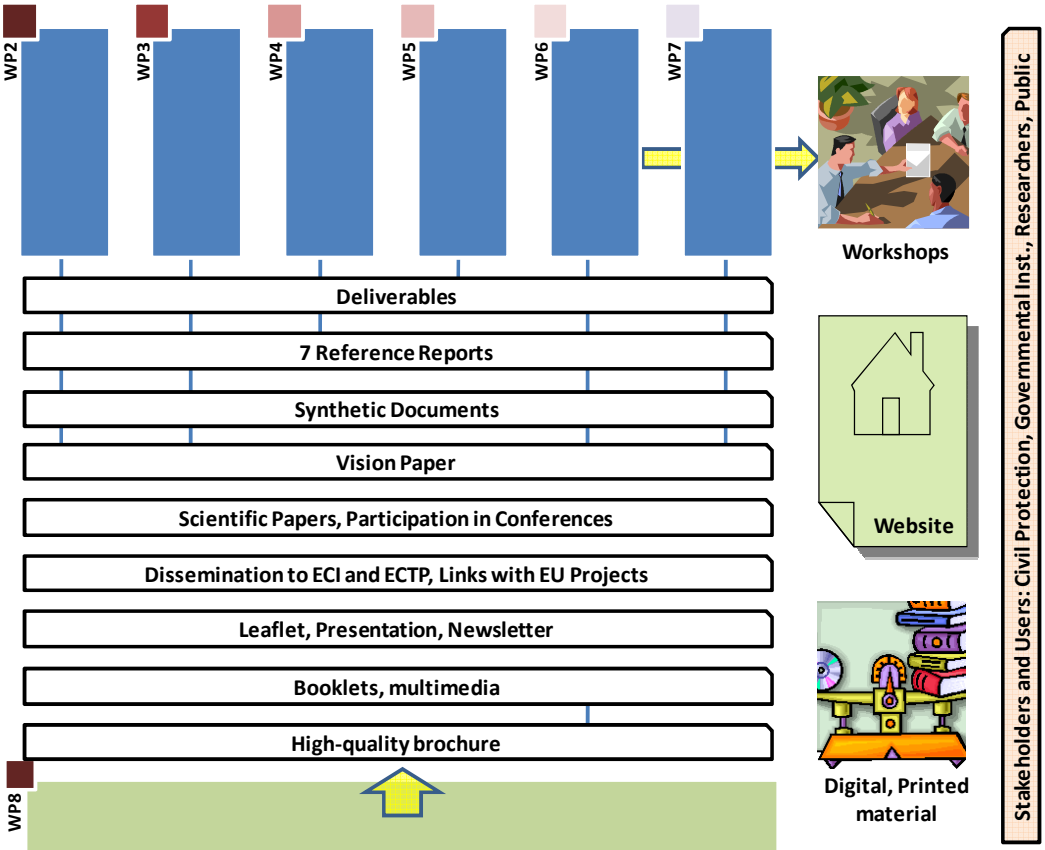
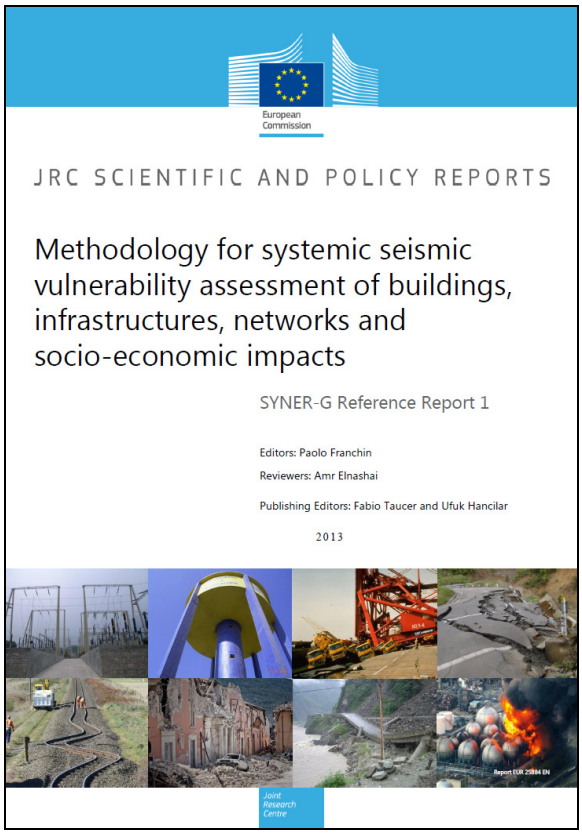


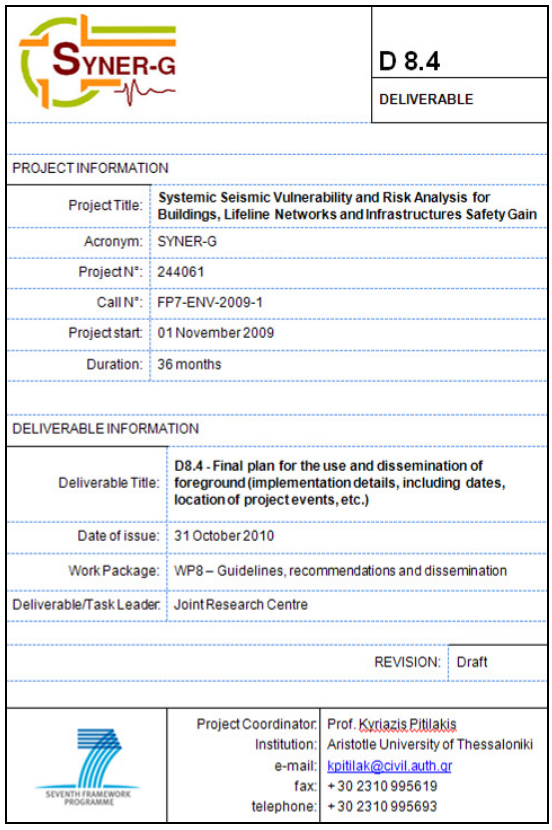
Fig. 26 Graphical representation of SYNER-G Dissemination scheme

Table 1 Consolidated List for the production of the SYNER-G Reference Reports

#	Report Title	Contributors	Lead Editor	Reviewer	Target Addressees*
1	Methodology for systemic seismic vulnerability assessment of buildings, infrastructures, networks and socio-economical impacts	AMRA, AUTH, BRGM, KIT-U, UPAV, UROMA	**UROMA**	UILLINOIS	SC
2	Guidelines for typology definition of European physical assets for earthquake risk assessment	AUTH, BRGM, JRC, NGI, UPAT, UPAV, UROMA	**JRC**	UPAT	SC, TC, PA, CP
3	Development of inventory datasets through remote sensing and direct observation data for earthquake loss estimation	AUTH, BRGM, JRC, UPAV, VCE	**JRC, UPAV**	NGI	SC, TC, PA, CP
4	Guidelines for deriving seismic fragility functions of elements at risk: Buildings, lifelines, transportation networks and critical facilities	AUTH, BRGM, KIT-U, METU, NGI, UPAT, UPAV, UROMA	**NGI**	AMRA	SC, TC, CP
5	Guidelines for the consideration of socio- economic impacts in seismic risk analysis	AMRA, KIT-U, METU, NGI	**KIT-U**	AUTH	SC, TC, PA, CP
6	Systemic seismic vulnerability and loss assessment: Validation studies	AMRA, AUTH, KIT-U, METU, UPAT, UROMA, VCE	**AUTH**	NGI, METU	SC, TC, PA, CP
7	Systemic seismic vulnerability and loss assessment: Software Users Manual	KIT-U, UROMA, VCE	**VCE**	METU	SC, TC, CP

*Target Addresses [Examples (non-exhaustive)]: Scientific community, Technical community, Public administration (Commission, National, Regional, Local), Civil protection Agencies
** The final reviewer will be assigned during the meetings





SYNER-G

D 8.4

DELIVERABLE

PROJECT INFORMATION

Project Title:	Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain
Acronym:	SYNER-G
Project N°:	244061
Call N°:	FP7-ENV-2009-1
Project start:	01 November 2009
Duration:	36 months

DELIVERABLE INFORMATION

Deliverable Title:	D8.4 - Final plan for the use and dissemination of foreground (implementation details, including dates, location of project events, etc.)
Date of issue:	31 October 2010
Work Package:	WP8 – Guidelines, recommendations and dissemination
Deliverable/Task Leader:	Joint Research Centre
REVISION:	Draft

SEVENTH FRAMEWORK PROGRAMME

Project Coordinator:	Prof. Kyriazis Pitilakis
Institution:	Aristotle University of Thessaloniki
e-mail:	kpitilak@civil.auth.gr
fax:	+ 30 2310 995619
telephone:	+ 30 2310 995693

Fig. 27 Cover page: SYNER-G Reference Reports and Deliverables

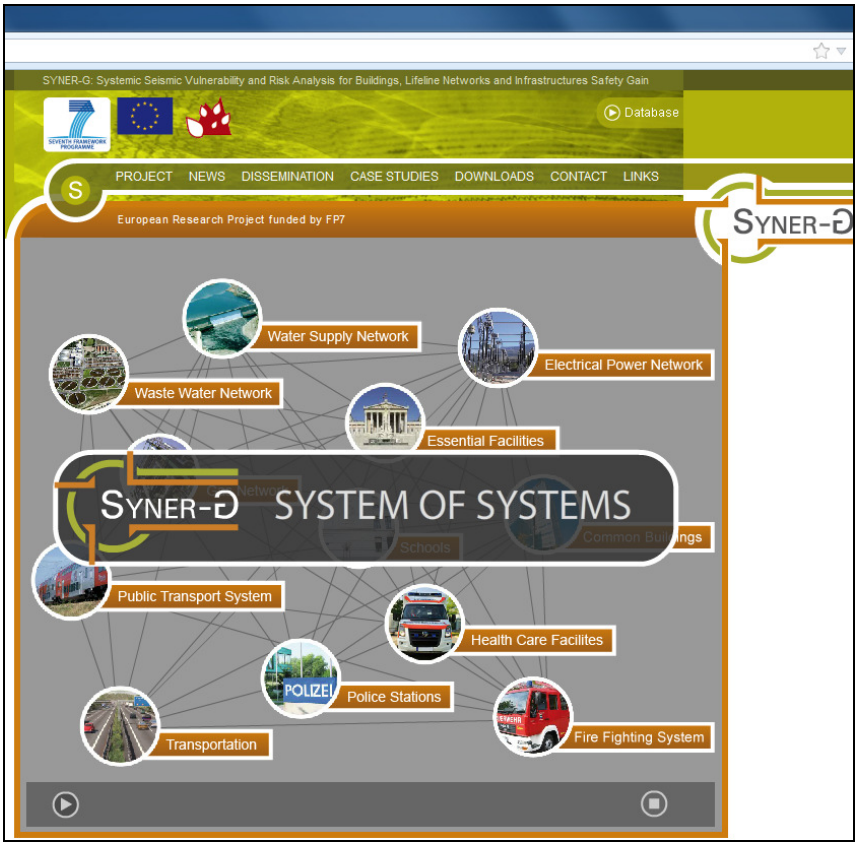


Fig. 28 Public website, homepage http://www.vce.at/SYNER-G/

Fig. 29 Project leaflet

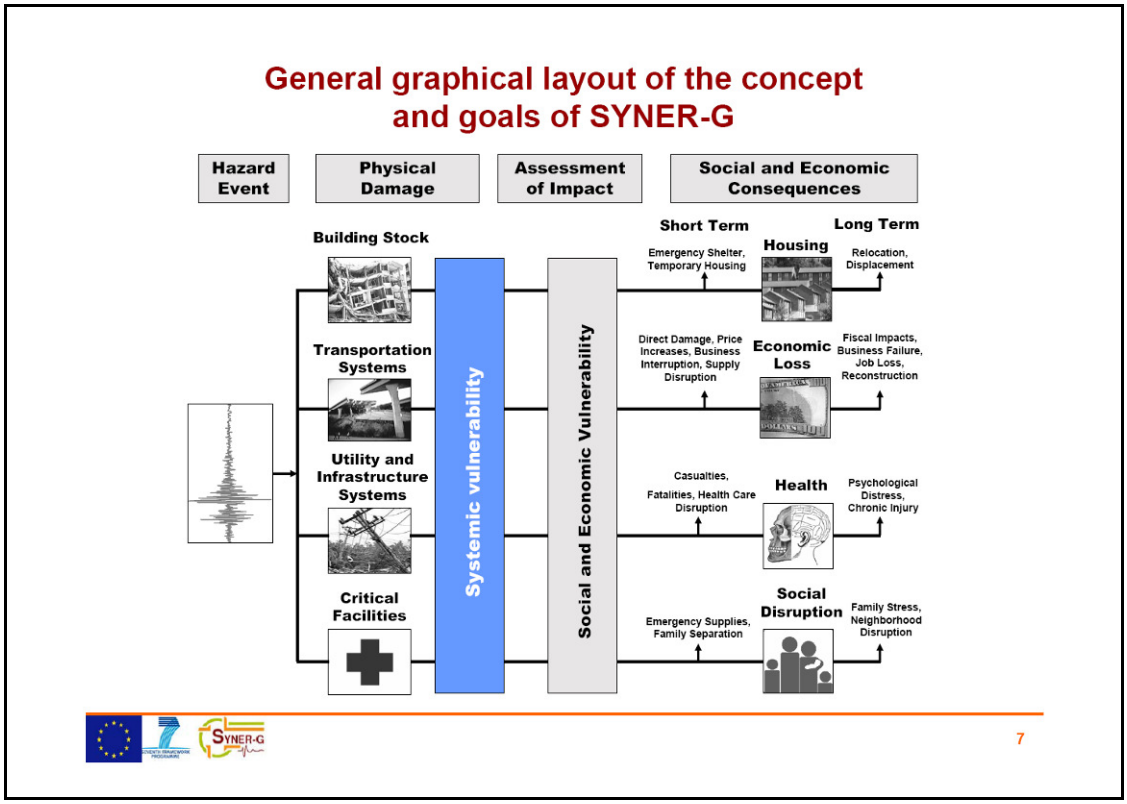


Fig. 30 Project presentation

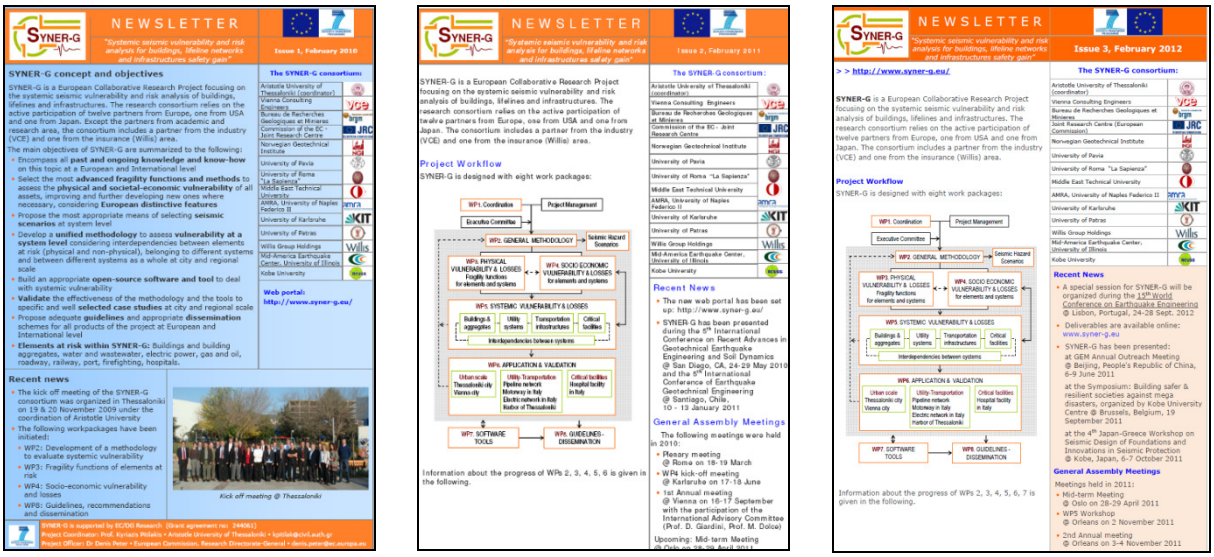


Fig. 31 Newsletters 1 (month 3), 2 (month 15) and 3 (month 27)

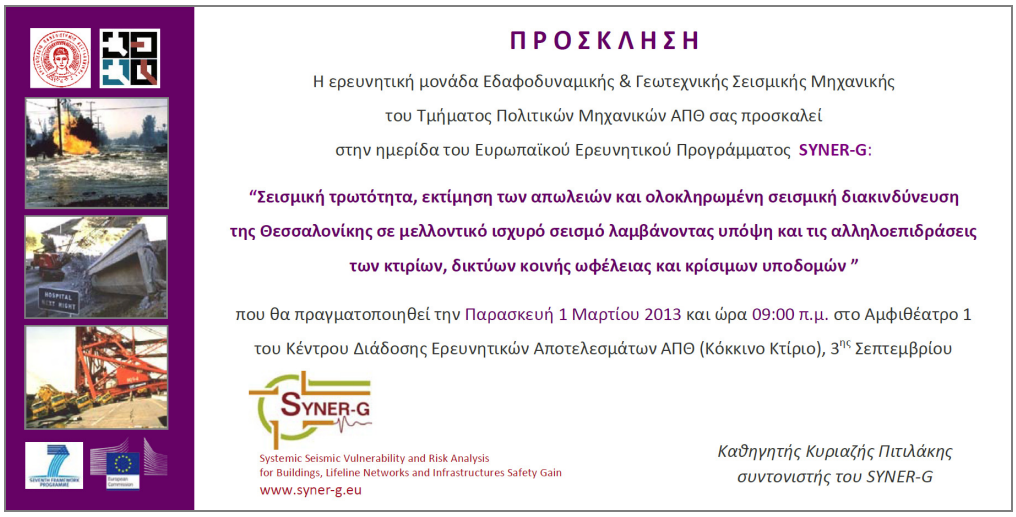


Fig. 32 Invitation to the SYNER-G Technical Workshop in Thessaloniki

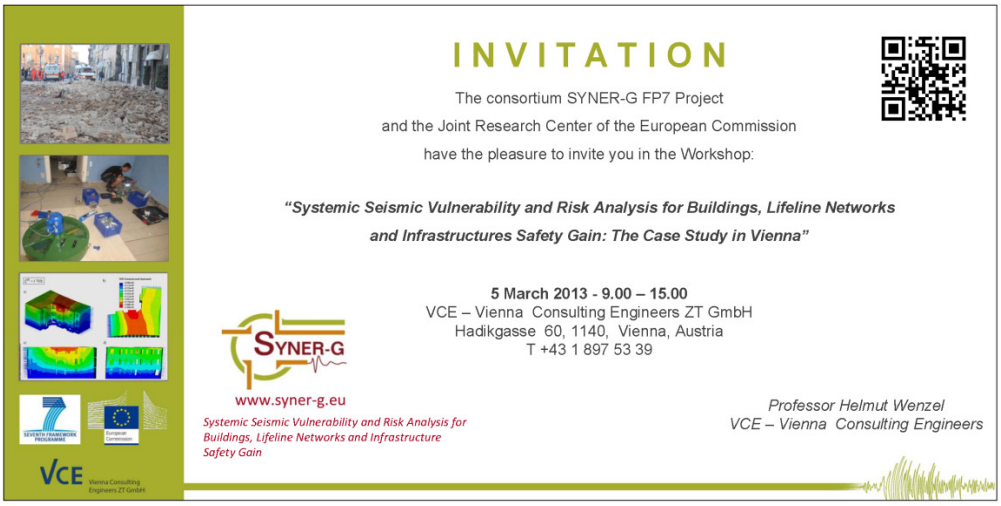


Fig. 33 Invitation to the SYNER-G Technical Workshop in Vienna

SYNER-G
www.syner-g.eu

SYSTEMIC SEISMIC VULNERABILITY AND RISK ANALYSIS
FOR BUILDINGS, LIFELINE NETWORKS AND INFRASTRUCTURES
SAFETY GAIN

FINAL WORKSHOP

Milano, 21-22 March 2013

"Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain: Methodology and Applications to Selected Case Studies in Europe"

NH President Hotel, Largo Augusto 10, Milano, Italy

PROGRAMME

Thursday, 21 March 2013				
Session Chairs	**Time**	**Title**	**Responsible**	**Duration**
	09:00	Welcoming of the participants		
K. Pitilakis A. Pinto F. Taucer S. Argyroudis	09:30	Opening of the workshop	K. Pitilakis, AUTH A. Pinto, JRC	10'
	09:40	The SYNER-G project	K. Pitilakis, AUTH	30'
	10:10	The SYNER-G integrated methodology and tools for systemic seismic vulnerability analysis of complex systems	P. Franchin, UROMA	30'
	10:40	Framework for seismic hazard analysis of spatially distributed systems	G. Weatherhill, UPAV	20'
	11:00	Typology definition of European physical assets for earthquake risk assessment	U. Hancilar, Bogazici Univ. (formerly at JRC)	20'
	11:20	*Coffee break*		*30'*
P. Franchin G. Weatherhill	11:50	Fragility functions for physical elements at seismic risk: the SYNER-G approach	A.M. Kaynia, NGI	20'
	12:10	The SYNER-G fragility manager tool	H. Crowley, UPAV	20'
	12:30	Framework for systemic socio-economic vulnerability and loss assessment	B. Khazai, KIT	20'
	12:50	Systemic vulnerability specification	P. Gehl, BRGM	20'
	13:10	Discussion	all	10'
	13:20	*Lunch break*		60'
B. Khazai K. Kakderi	14:20	The SYNER-G platform	D. Schaefer, VCE	20'
	14:40	Fragility curves for buildings and bridges for the city of Thessaloniki	G. Tsionis, UPAT	15'
	14:55	Damages and losses for buildings and lifeline for the city of Thessaloniki	K. Pitilakis, AUTH S. Argyroudis, AUTH	40'
	15:35	*Coffee break*		*25'*

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Fig. 34 Detailed program of the SYNER-G Final Workshop (Page 1) http://www.vce.at/SYNER-G/files/dissemination/finalworkshop.html)

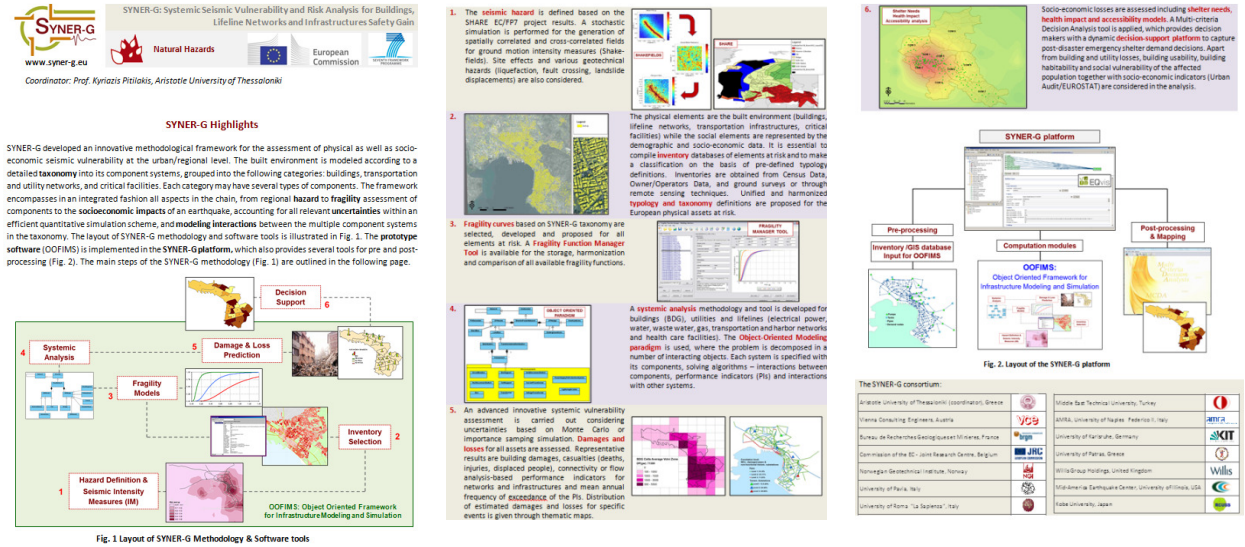

Fig. 35 SYNER-G Demo

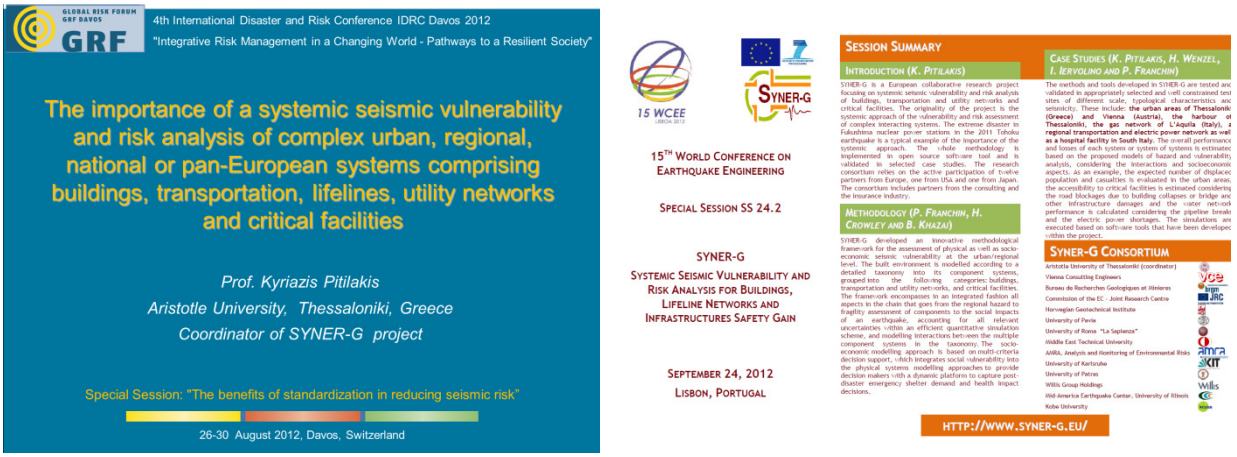

Fig. 36 SYNER-G Special Seminars: IDRC 2012 and 15WCEE

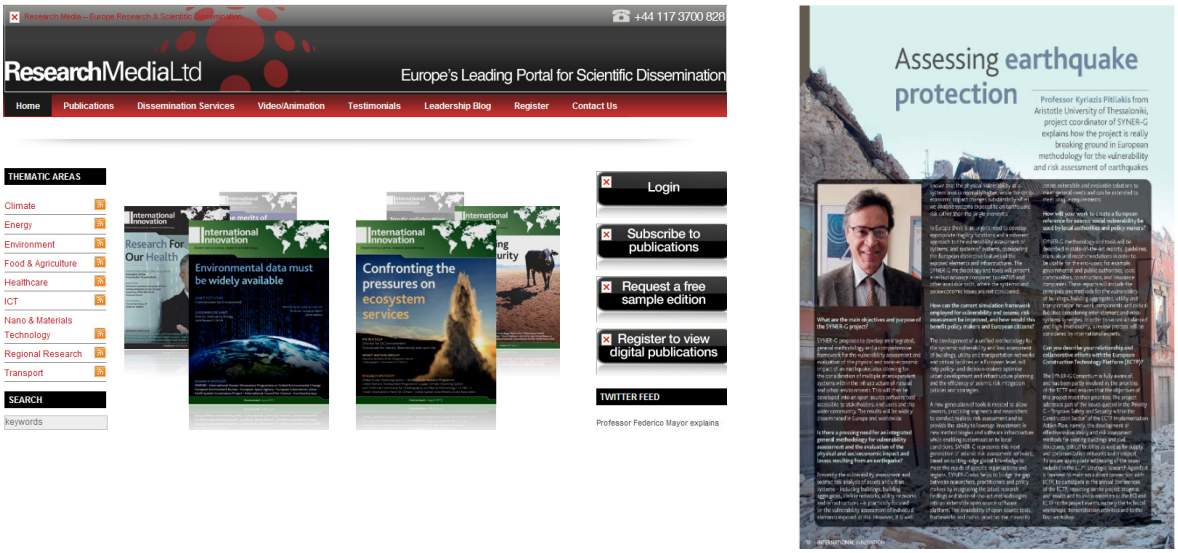

Fig. 37 ResearhMedia Ltd publication www.researchmedia.eu

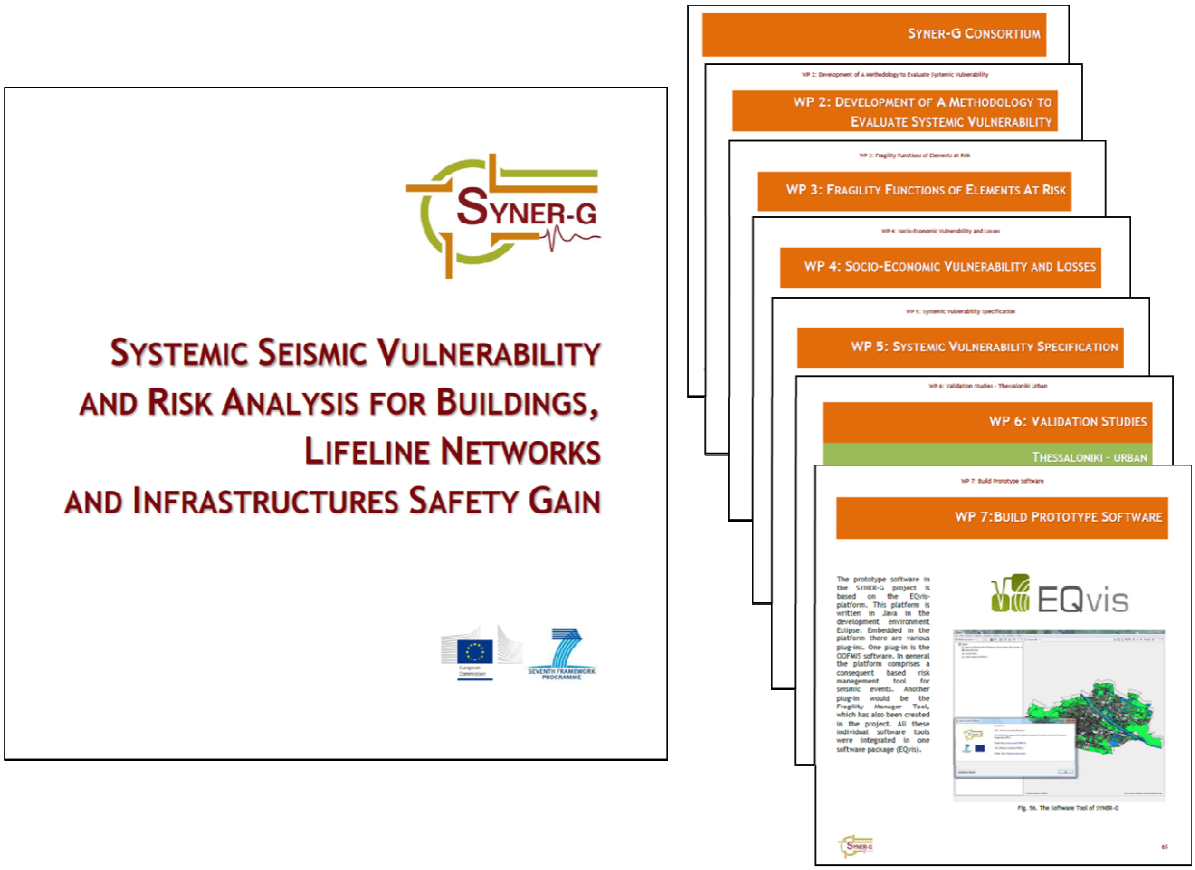

Fig. 38 High-Quality Brochure

(*http://www.vce.at/SYNER-G/pdf/download/SYNER-G_brochure_2013.pdf*)